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ABSTRACT

The 1971-1972 annual report on Stanford University's project to develop and research computer-assisted instruction curricula for deaf students describes the full range of project activities for the year. The programs available to the schools are described, along with the participating systems and research conducted during the year to improve the courses. (RH)

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ANNUAL REPORT

Project No. 14-2280
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J. D. Fletcher, D. T. Jamison, B. W. Searle, R. L. Smith
Institute for Mathematical Studies in the Social Sciences
Stanford University
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COMPUTER-ASSISTED INSTRUCTION FOR THE DEAF AT STANFORD UNIVERSITY

January 8, 1973

Department of Health, Education, and Welfare

U.S. Office of Education
Bureau of Education for the Handicapped

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Jaclyn Caselli
Dir. of Acquisitions

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Introduction

This project continued research and development of curriculums for hearing impaired students using computer-assisted instruction (CAI). Curriculums developed by the Institute for Mathematical Studies in the Social Sciences (IMSSS) at Stanford University were used by more than 1,000 hearing impaired students during the 1970-71 school year and by more than 2,000 hearing impaired students during the 1971-72 school year. The project has generated much interest and support among educators in schools for the deaf and hard of hearing throughout the country.

The project was begun in June 1970 under Grant No. OEG-0-70-4797(607) as OE Project No. 14-2280. Present funding continues through October 31, 1972. The original proposal was submitted by IMSSS to the Bureau of Education for the Handicapped on October 16, 1969 and revised on April 1, 1970. The original proposal covered the three and a half-year period starting June 1, 1970 and ending December 13, 1973.

1970-71

The original proposal for this project was prepared by IMSSS in cooperation with three schools for the deaf and one school district that had already indicated great interest in having CAI curriculum for their deaf students. These were the California School for the Deaf in Berkeley, California; the Kendall School for the Deaf in Washington, D.C.; the San Jose Unified School District in San Jose, California, which has day classes for the deaf in four schools; and the Texas School for the Deaf in Austin, Texas. Students at all of these schools regularly used Stanford CAI courses during the 1970-71 school year.

In addition to the four schools that participated in the original proposal, one other school and one other school district joined the project for the 1970-71 school year. These were the Model Secondary School for the Deaf (MSSD), which is located near Kendall School on the campus of Gallaudet College in Washington, D.C., and the Palo Alto Unified School District in Palo Alto, California, which used CAI for deaf students from three schools. Both of these were able to find funding from other sources to support their student terminals. The Palo Alto School District included the Stanford terminals as part of a larger experiment using CAI for deaf students; they also used teacher-prepared CAI curriculum implemented on their own computer system. The final report on this project is available from Mrs. Ruth Jackson, Program for the Deaf and Hard of Hearing, Palo Alto Unified School District, 25 Churchill Avenue, Palo Alto, California.

During the 1970-71 school year there were 60 terminals in operation at the participating schools. Over 1,000 deaf students used one or more of the Stanford CAI courses. Detailed information about distribution of teletypes and course usage is given in Sections II and III of the annual report for 1970-71.

1971-72

All of the schools that participated in the project during the 1970-71 school year continued during the 1971-72 school year, and several new schools joined the project. The schedule originally proposed that one new school with 15 terminals would be added during the 1971-72 school year. However, so many schools for the deaf expressed interest in having CAI terminals that the decision was made to offer teletypes on a 50-50 cost-sharing basis and thereby to allow more schools to join. The Florida State School for the Deaf and the Blind in St. Augustine, Florida, was added October 1. The Florida School is a state residential school that has about 475 students in grades kindergarten through high school. Ten terminals were installed in the Oklahoma School for the Deaf in Sulphur, Oklahoma. The Oklahoma School is also a state residential school; it has approximately 225 students ranging from preschool through high school.

Five new locations were added in Texas under the state's day school program. Texas has seven county-wide day schools for deaf students, and CAI terminals were installed in five of these schools. Four terminals were installed in the Houston Independent County-Wide Day School in Houston, Texas; two in the Bexar County Day School for the Deaf in San Antonio, Texas; three in the Dallas County Day School for the Deaf in Dallas, Texas; two in the Tarrant County Day School for the Deaf in Fort Worth, Texas; one in the Beaumont Bi-County Wide Day School for the Deaf in Beaumont, Texas.

The telephone line costs for the Texas county-wide day schools, the Texas School for the Deaf in Austin, and the Oklahoma School for the Deaf in Sulphur were reduced by the creation of a combined circuit. A Micro 800 computer was installed at the Texas School in Austin in the same room as the teletypes. The Micro 800 will allow 48 data channels to be multiplexed; before, with Collins equipment, only 15 channels could be multiplexed.

All schools for the hearing impaired that participated in the IMSSS project during the 1971-72 school year, including number of CAI terminals installed and percentage of financial support provided by the project's OE funds, are listed in Table 1.

Summary of CAI Curriculums Available to Participating Schools

All CAI curriculums developed by IMSSS are available to students in the participating schools for the deaf. Some IMSSS curriculums, such as reading (grades K-3), French, and Russian, are inappropriate because they require audio. However, most of the curriculums, even though not specifically designed for hearing-impaired students, are being used successfully by the participating schools. A list of IMSSS curriculums with the numbers of hearing-impaired students who used them in 1971-72 is presented in Table 2. Brief descriptions of curriculums other than the math strands and language arts courses discussed later follow.

TABLE 1

Participating Schools in 1971-72

School	Terminals	Support*
California School for the Deaf at Berkeley	15	100
Florida State School for the Deaf and the Blind	8	50
Kendall School for the Deaf	12	100
Model Secondary School for the Deaf	8	0
Oklahoma School for the Deaf	10	50
Palo Alto Unified School District (February 10, 1972-June 10, 1072)	2	0
San Jose Unified School District		
Bachrodt Elementary School	2	100
Hester Elementary School	2	100
Hoover Junior High School	1	100
San Jose High School	1	100
Texas County-Wide Day Schools		
Houston Independent County-Wide Day School	4	50
Bexar County Day School for the Deaf (San Antonio)	2	50
Dallas County Day School for the Deaf	3	50
Tarrant County Day School for the Deaf (Fort Worth)	2	50
Beaumont Bi-County Wide Day School for the Deaf	1	50
Texas School for the Deaf	15	100
Total	88	

*Percentage of financial support of CAI terminals provided by OE funds.

TABLE 2

Institute CAI Curriculums Used by Participating Schools for the Deaf, 1971-72

Curriculum	Number of students
Algebra	83
Basic English	165
Computer Programming in AID	93
Computer Programming in BASIC	124
Language Arts	1071
Logic and Algebra	216
Elementary Mathematics (Strands)	2146
Arithmetic Word Problem Solving	107
Total Students	2279

Logic and Algebra. This course is designed for secondary school students. The first year introduces numerical and sentential variables, formation of algebraic terms and sentences, and truth conditions of simple sentences. The second year of the course is concerned with the foundations of algebra. From a small set of axioms and rules of inference the properties of the field of rational numbers are developed.

Algebra. Algebra is a self-contained tutorial course designed for secondary school students. It teaches the basic properties of arithmetic operations, simplifying and solving equations and the properties of inequalities. Each lesson contains instruction, printed homework, corrections of homework problems on the computer and a quiz. There are currently 25 lessons available. The course is still under development.

Basic English. This course is designed to provide secondary school students with practice in problem areas of standard English usage. The objective of the course is to diagnose and correct the twelve most common usage errors: run-on sentences, sentence fragments, incorrect principal parts of the verb, confusion of adjectives and adverbs, lack of agreement between subject and verb, lack of agreement between pronoun and antecedent, incorrect case of pronouns, vague or indefinite pronomial reference, dangling elements, misplaced modifiers, errors in comparative forms of adjectives and adverbs, and double negatives.

Computer Programming in BASIC. This is a self-contained course for secondary students. It provides an introduction to programming for students without a knowledge of algebra. The course consists of 50 lessons, about one hour in length, plus summaries, reviews, and self tests.

Computer Programming in AID. This is a self-contained, tutorial program that teaches the use of Algebraic Interpretive Dialogue (AID), a high-level algebraic language. The course was designed for junior college students and requires at least one year of algebra background. The course consists of 50 lessons, about one hour in length, plus summaries, reviews, tests, and extra-credit problems.

Arithmetic Word Problem Solving. The course presents a graded series of 700 arithmetic word problems (with stored text and program-generated values). The student uses the computer to do the calculations, and is thereby free to concentrate on problem solutions which he enters as algebraic strings (e.g., $A + B \times 3$). The program contains various levels of generated and explicit hints for the student. The course can be used in conjunction with the elementary mathematics program. The problems can be presented in English or in Spanish.

Games

There are several games available to student users. Although they are called games and are entertaining to use, they are seldom without redeeming pedagogical value.

Bagels. This game is properly called Pico-Fermi-Bagels. The program creates a 3-digit number at random, and the student-player is to try to guess it. If one of the digits he guesses is correct but in the wrong position, he is told PICO. If one of the digits he guesses is correct and in the correct place, he is told FERMI. If none of the digits he guesses is correct, he is told BAGELS. He has 20 chances to guess the number.

Hangman. Hangman is the familiar game that most American children play in elementary school. In the IMSSS version, a definition or hint for a word is given, and the student-player is given six chances to guess the word by giving the letters that belong in it. The figure being hanged is "drawn" by the teletypewriter. Three vocabulary lists are available for the game. Before beginning, the student-player must select the easy, medium, or hard list. Hangman is also available in a Spanish version.

Poster. Poster creates a poster by taking in any number of lines of text and enlarging the characters in each line to fill up the (8-inch) width of the teletypewriter paper.

Spell. In Spell, a word is typed and the student-player must indicate if it is spelled correctly or incorrectly. If the word is incorrect, the student-player must supply the correct spelling.

Spanish. In Spanish, a word is given in Spanish or English, and the student-player must translate it to English or Spanish, respectively. All instructions and hints are given in Spanish.

Tictac. Tictac is tic-tac-toe presented by teletypewriter. The student-player may assign to the computer (and to himself by implication) any one of four levels of ability: beginner, average, good, and grand master.

The Stanford CAI System

The central processor for the Institute's computer system is a Digital Equipment Corporation PDP-10. In addition to core memory, short-term storage of programs and student information is provided by eight 180,000,000-bit disk modules. Long-term storage of student response data is provided by magnetic tape. About 280,000,000 bits of information can be stored by the system on one magnetic tape. Communication with remote student terminals in participating schools is provided by telephone lines. Fifteen student terminals anywhere in the country can communicate with the Institute system using only one ordinary telephone line. For communication with clusters of 16 or more terminals, high-speed data lines routinely provided by the telephone company are used. In 1971-72, more than 180 terminals were connected to the Institute system. About 90 of these terminals could be used simultaneously with no appreciable detriment in the system's speed of response. Any curriculum or other program could be run at any time on any student terminal.

The student terminals themselves are "KSR Model 33" teletypewriters. These teletypewriters communicate information to and from the central computer system at a rate of about 10 characters per second. They provide no audio, visual, or graphic capability, but their cost is about one-tenth of terminals that do. Despite their limitations, these inexpensive terminals have permitted development of CAI that has produced dramatic gains in pedagogical achievement for hearing students as Suppes and Morningstar (1970), Fletcher and Atkinson (1972), and others have reported. For that matter, Jamison, Fletcher, Suppes, and Atkinson (1972) have argued that for cost-effectiveness, CAI, using satellite communication, is superior to all other methods in providing compensatory education.

Mathematics Strands Program

Introduction

Three experiments were performed during 1971-72 to evaluate the effectiveness of the Stanford/CAI Mathematics Strands curriculum with deaf and hard of hearing students. Experiment I examined the effect of number of math strands sessions on test performance. Experiment II investigated the feasibility of successfully predicting the amount of on-line instructional intervention each student needs to meet an individually prescribed performance goal. Intervention took the form of extra sessions at the terminal. Both Experiment I and II used as external pre- and post-tests a modified Stanford Achievement Test (MSAT), administered to the student at the computer terminal. Experiment III tested the concurrent validity of grade placement (GP) measured by the MSAT, by comparing MSAT GP with GP measured by paper and pencil administrations of the Stanford Achievement Test (SAT). Results from Experiments I and III are reported by Suppes, Fletcher, Zanotti, Lorton, and Searle (1972); results from Experiment II are reported by Suppes, Fletcher, and Zanotti (1972).

The students who participated in these studies were chosen from among the entire population of deaf students who received CAI in mathematics and language arts during 1971-72. Degree of hearing loss among the students is essentially that adopted for admission standards by the schools for the deaf participating in the experiment. Usually, this loss is at least 60 decibels in the better ear. Students selected by the schools for CAI generally represent a cross section of their secondary school population. Some students may be significantly handicapped in ways other than that of hearing loss, but these additional handicaps will not have prohibited them from meeting elementary school graduation requirements.

Description of the IMSSS Mathematics Strands Program

The objectives of the program are (1) to provide supplementary individualized instruction in elementary mathematics at a level of difficulty appropriate to each student's level of achievement, (2) to allow acceleration in any concept area in which a student demonstrates proficiency and

repeated drill in areas of deficiency, and (3) to provide a daily profile report of each student's progress through the curriculum.

A strand is a series of problems of the same operational type (e.g., number concepts, addition, subtraction, fractions) arranged sequentially in equivalence classes according to their relative difficulty. The 14 strands in the program and the grade levels spanned by each strand are

Number Concepts	1.0-7.9
Horizontal Addition	1.0-3.9
Horizontal Subtraction	1.0-3.4
Vertical Addition	1.0-5.9
Vertical Subtraction	1.5-5.9
Equations	1.5-7.9
Measurement	1.5-7.9
Horizontal Multiplication	2.5-5.4
Laws of Arithmetic	3.0-7.9
Vertical Multiplication	3.5-7.9
Division	3.5-7.9
Fractions	3.5-7.9
Decimals	4.0-7.9
Negative Numbers	6.0-7.9

A student in the strands program will work on fewer than 14 strands; the actual number will depend on his grade level and performance. The strands approach provides a high degree of individualization because each student's lesson is prepared for him daily by the computer, the lessons are presented as mixed drills at a level of difficulty in each concept determined by the student's prior performance in each concept, and the student moves up each strand at his own pace.

The Test Instrument: The Modified SAT

Description of the SAT. The arithmetic computation section of the Stanford Achievement Test (SAT) was used as a guide for the development of an achievement test (MSAT) that can be administered at the computer terminal. The arithmetic computation sections of three SAT batteries, Primary II, Intermediate I and Intermediate II, were used as models. For all three levels, forms W and X were examined.

Computation problems on the Primary II test are worked in the test booklet. All of the questions on the computation sections of the Intermediate level tests (I and II) are multiple choice and responses are entered in the test booklet or on a standard answer sheet. The responses are letters between a and j. Each question has four or five possible responses; the letters a-d and a-e are used for one question, the letters e-h or f-j for the next question.

Several properties of the tests are shown in Table 3. The table contains, for each level, the number of problems, the time allowed for administration, and the grade placement corresponding to error rates of .75, .50 and .25. These last figures are shown separately for forms W and X.

TABLE 3

Characteristics of Computation Section of the SAT

Test Level	Number of Problems	Time Min.	Placement on Form W			Placement on Form X		
			.25	.50	.75	.25	.50	.75
Primary II	60	30	2.4	3.4	4.4	3.2	3.3	4.4
Intermediate I	39	35	3.5	4.6	5.8	3.5	4.7	6.0
Intermediate II	39	35	4.4	6.1	8.5	4.6	6.2	8.7

Construction of the MSAT. Three sets of parallel items were constructed for each item occurring in the computation section of the SAT. The method used to construct items depended on whether or not the item was of a type that appears in the math strands CAI curriculum.

Each SAT problem of a type that occurs in the CAI curriculum was labeled with the equivalence class number into which it fits. Both forms (W and X) were examined and labeled. If similar items for both forms fell in the same equivalence class, three items from that equivalence class were used. If this was not the case, a new class definition was constructed that included the attributes of both classes, and three problems were written to fit this class definition. The class numbers obtained are presented in Table 4 for Primary II, Table 5 for Intermediate I, and Table 6 for Intermediate II.

If a test problem was of a type that does not occur in the strands curriculum, a new "class" definition was written that describes the salient features of the exemplars from both tests forms. Then three items were written using the class definition.

A careful analysis was made of the answer choices presented in Intermediate I and II. For both test levels there are four problems for which the correct answer is "not given." Four problems were similarly constructed for the MSAT. The wrong answers to addition problems differ from the correct answer in one digit that may occur in any but the left-most position. The wrong answers to subtraction problems differ from the correct answer in one digit that may occur in any but the left-most position, or the left-most digit may be one less than that of the correct answer.

TABLE 4

Characterization of SAT Problems by Math Strands Equivalence Class

Primary II

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
VSU 2.00	1	3	1
VSU 2.10	2	2	2
VSU 2.10	3	6	3
VSU 2.10	4	5	4
VSU 2.10	5	4	5
VSU 2.10	6		6
VSU 1.80		1	6
HAD 2.00	7		7
HAD 2.10		7	7
HSU 2.60	8	8	8
VAD 2.65	9	10	9
VAD 3.10	10	9	10
VAD 3.10	11	11	11
HAD 2.80	12	12	12
VSU 2.95	13	13	13
VSU 2.70	14	14	14
VSU 2.95	15	15	15
HSU 2.20	16	16	16
VAD 4.00	17	17	17
VAD 4.00	18	18	18
VAD 4.00	19	19	19
VAD 4.00	20	20	20
HAD 2.80	22	21	21
HAD 2.80	21	22	22
HAD 2.80	23	23	23
HAD 2.80	24	24	24
HAD 2.80	25	25	25

TABLE - (cont'd)

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
(None: See Note 1)	26	26	26
VSU 3.15	27	27	27
VSU 3.15	28	28	28
VSU 3.15	29	29	29
VSU 3.15	30	30	30
VSU 3.15	31	31	31
VSU 3.15	32	32	32
VAD 4.40	33	33	33
VAD 5.10	34	34	34
VSU 4.10	35	35	35
VSU 4.80	36	36	36
VAD 5.70	37	37	37
HMU 3.60	38	38	38
DIV 7.40 (See Note 2)	39	39	39
HMU 3.85	40	40	40
DIV 7.40 (See Note 2)	41	41	41
VMU 4.50	42	42	42
DIV 4.95	43	43	43
VMU 4.50	44	44	44
DIV 4.95	45	45	45
VMU 4.50	46	46	46
DIV 4.95	47	47	47
VMU 4.55	48	48	48
DIV 4.95	49	49	49
VMU 4.90	50	50	50
DIV 4.95	51	51	51
(None: See Note 3)	52	52	52
(None: See Note 4)	53	53	53
(None: See Note 3)	54	54	54

TABLE 4 (cont'd)

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
(None: See Note 4)	55	55	55
(None: See Note 5)	56	56	56
VMU 5.00	57	57	57
(None: See Note 5)	58	58	58
VMU 5.00	59	59	59
(None: See Note 5)	60	60	60

Notes:

Note 1: Class definition is $19A + B = \cdots$, where $A + B > 9$.

Note 2: Equations class 4.25.

Note 3: Class definition is $A \times BCD = \cdots$.

Note 4: Class definition is $ABC/D = \cdots$, no remainder.

Note 5: Class definition is $A\sqrt{BCD}$ $A > B$, no remainder.

TABLE 5

Characterization of SAT Problems by Math Strands Equivalence Class

Intermediate I

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
VAD 3.10	1	1	1
VSU 3.15	2	2	2
VAD 3.60	3	4	3
HAD 3.70	4	6	4
VMU 3.85	5	3	5
VMU 3.85	6	5	6
(None: See Note 1)	7	8	7
VSU 4.15	8	7	8
VSU 4.15	9	9	9
VSU 4.15	10	11	10
DIV 4.95	11	12	11
VMU 5.00	12	10	12
(None: See Note 2)	13	14	13
(None: See Note 3)	14	17	14
VAD 5.50	15	13	15
VSU 4.90	16	19	16
VAD 5.90	17	16	17
(None: See Note 4)	18	18	18
VAD 5.10	19	15	19
(None: See Note 5)	20	20	20
DIV 5.30	21	21	21
(None: See Note 6)	22	22	22
VMU 5.00	23	24	23
(None: See Note 5)	24	25	24
(None: See Note 6)	25	23	25
(None: See Note 7)	26	30	26

TABLE 5 (cont'd)

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
(None: See Note 6)	27	26	27
DIV 6.30	28	34	28
DIV 5.50	29	29	29
DIV 5.50	30	33	30
(None: See Note 7)	31	31	31
VMU 6.00	32	32	32
DIV 5.50	33	33	33
DIV 5.35	34	34	34
VMU 6.70	35	35	35
VMU 6.40	36	37	36
(None: See Note 8)	37	36	37
(None: See Note 9)	38	38	38
VMU 6.60	39	39	39

Notes:

Note 1: Class definition is AB + CD + E = ---,
B + D + E > 9, A + C > 9.

Note 2: Class definition is A × BCD = ---, A < 5.

Note 3: VSU 5.20 with $ and decimal added.

Note 4: Class definition is ABC/D = ---, no remainder.

Note 5: Class definition is $\begin{array}{r} 1ABCD \\ -\ EFGH \\ \hline \end{array}$ with borrows everywhere.

Note 6: Class definition is "1/A of BCD", no remainder.

Note 7: Class definition is $A\overline{/BCDE}$ where A divides BC and A divides DE.

Note 8: VMU 6.30 with $ and decimal added.

Note 9: FRA 5.60 of "×".

TABLE 5

Characterization of SAT Problems by Math Strands Equivalence Class

Intermediate II

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
(None: See Note 1)	1	1	1
VAD 5.50	2	2	2
(None: See Note 2)	3	3	3
VAD 5.70	4	4	4
VAD 5.90	5	11	5
(None: See Note 3)	6	6	6
(None: See Note 3)	7	5	7
VAD 5.70	8	12	8
DIV 5.50	9	13	9
DIV 5.50	10	9	10
VMU 6.30	11	8	11
VMU 6.40	12	7	12
(None: See Note 3)	13	10	13
FRA 4.55	14	16	14
(None: See Note 4)	15	17	15
DIV 6.60	16	18	16
VMU 6.60	17	20	17
VMU 6.70	18	14	18
DIV 5.50	19	19	19
DIV 6.50	20	15	20
DIV 6.60	21	21	21
FRA 6.40	22	26	22
(None: See Note 5)	23	23	23
(None: See Note 6)	24	22	24
FRA 5.60	25	24	25
(None: See Note 7)	26	28	26

TABLE 6 (cont'd)

Equivalence Class Number	Problem Number Form X	Problem Number Form W	Problem Number MSAT
DEC 7.35	27	25	27
FRA 6.45	28	29	28
FRA 7.30	29	30	29
(None: See Note 8)	30	33	30
(None: See Note 9)	31	31	31
FRA 6.85	32	32	32
MEA 5.10	33	29	33
(None: See Note 10)	34	35	34
(None: See Note 11)	35	34	35
(None: See Note 12)	36	36	36
(None: See Note 13)	37	39	37
(None: See Note 14)	38	36	38
(None: See Note 15)	39	37	39

Notes:

Note 1: Class definition is $A\overline{)BCD}$ where A < B and remainder = 0.

Note 2: VSU 3.70 with $ and decimal added.

Note 3: Class definition is $\begin{array}{r} 1ABCD \\ -\ EFGH \end{array}$ with borrows everywhere.

Note 4: Class definition is "Find the average of A,B,C,D", average is an integer.

Note 5: Class definition is $\begin{array}{r} A\ B/C \\ -D\ E/F \end{array}$ where A = D + 1, D may be 0, C(F) is a multiple of F(C) and B/C < E/F.

Note 6: Class definition is $\begin{array}{r} A/B \\ +1\ C/D \end{array}$ where B and D are relatively prime and A/B + C/D < 1.

Note 7: Class definition is $\begin{array}{r} 1AB \\ \times\ C.D \end{array}$ where C is 0 or 1.

TABLE 6 (cont'd)

Note 8: Class definition is A/B = ••• where A is a 3 or 4 digit number with 2 decimal places and B divides A.

Note 9: Class definition is "Find the average of A,B,C" where A,B,C are measures.

Note 10: Class definition is 1/A of B = ••• where B is a measure.

Note 11: Class definition is $\begin{array}{r} \$AB.CD \\ \times \quad EF \\ \hline \end{array}$.

Note 12: DIV 6.40 with instruction "What is the quotient rounded to tenths?"

Note 13: Class definition is "A is what percent of B?"

Note 14: Class definition is A/.B = •••, where B divides A.

Note 15: Class definition is "What is A percent of B?"

Two of the wrong answers to multiplication problems may be a pair of numbers that differ from each other in one digit and are one digit too short. If there is a two digit multiplier, one of these short answers is constructed by using only one of the digits of the multiplier. Other possible wrong answers differ from the correct answer in any digit except the left-most one. Decimal problems with numbers written with a dollar sign are treated as though they were integers. For most other decimal problems, either multiplication or division, the wrong answers differ from the correct answer in the placement of the decimal point. For these problems, four answers are chosen from

$$CA * 10^{K} \qquad -2 \leq K \leq 2$$

where CA is the correct answer.

Division problems occur in three formats: $A\overline{)B}$, $B \div A$, and $1/A$ of B. For all three types the answer choices are constructed in the same way. Some choices have a remainder and others do not, regardless of the correct answer remainder. The format used for presenting the answers changes in the middle of the Intermediate II test. For Intermediate I and the first part of Intermediate II, answer choices with remainders are written X, REM Y. For the second part of Intermediate II, most of the choices are written X Y/Z. Wrong answers were constructed by changing one of the digits of the quotient, and for those answers with a remainder, choosing a random remainder. Some remainders were larger than the divisor.

One dilemma was encountered in constructing answers for division problems. Two problems on the X form of Intermediate I and one on the W form had two technically correct answers. The following item exemplifies these problems.

$4\overline{)208}$

A) 42
B) 50, REM 8
C) 52
D) 5, REM 8
E) NOT GIVEN

C is the "correct" answer, but an argument can be made that B is also correct. This answer choice was not imitated in constructing wrong answers for the MSAT.

All of the items written for the MSAT are stored in the computer. A computer program constructs a pre- or post-test for a student by making a random selection among the three items written for each problem number. It is unlikely that two students will receive the same test. A record is kept of the items that comprise each student's test.

It is anticipated that the MSAT parallels the SAT in nearly every aspect. The major exception concerns the possibility for students taking

the paper and pencil SAT to return to problems already completed or skipped over. Students may skip any problem on the MSAT simply by typing the return key. However, once an MSAT problem is passed by a student there is no way for him to return to it. Some styles of responding appropriate for the SAT are inappropriate for the MSAT.

Administration of the MSAT. Tests are administered at the terminal, preferably at one sitting. If a student is not able to work at the terminal for a sufficiently long time to complete the test, it is continued at the next sign-on. The maximum time allowed to complete the test is the time allotted for administration of the computation section of the SAT, plus one-half the time it takes to type the test on the terminal.

The response mode on the MSAT is as close as possible to that required on the SAT. For multiple-choice items the student types a single letter, A, B, C, D or E. For constructed responses the student works the problem as a regular strand problem, with the program error response suppressed. The student is allowed only one response to a problem. He may alter his response, using the rubout key. When he has completed his answer, he types the return key. If a student working a multiple-choice problem types a number instead of a letter, he is told to type a letter and given another chance. As soon as the return key is typed the program moves to the next problem. There is no time limit for individual problems. Many of the problems will require pencil and paper computation.

The procedures that differ from the usual mode of responding at the teletype must be explained to the student. A message at the beginning of each test mentions the following:

1. using paper and pencil when necessary;
2. answering multiple-choice questions with a letter (for the Intermediate I and II);
3. using the return key after a response (for the Intermediate I and II);
4. using the return key to skip a problem;
5. using the rubout key to erase;
6. understanding the time limit for the entire test.

These six points and the printed instructions are explained and amplified by the CAI proctors before students take the MSAT. The instructions printed for the Primary II and the two intermediate forms of the MSAT are displayed in Figure 1. As in the SAT, students are given a non-graded sample problem before beginning the MSAT. Students are not given any results at the end of a test session. A coded number containing the score is printed at the end of the session for use by teachers.

Instructions for MSAT Primary II:

MODIFIED S. A. T. STRAND

THIS IS A SPECIAL TEST. YOU HAVE 33 MINUTES TO WORK ON IT. YOU MAY USE PENCIL AND PAPER.

TYPE THE RETURN KEY TO GET THE NEXT PROBLEM.

HERE IS A SAMPLE PROBLEM.

4 + 9 = 13

Instructions for MSAT Intermediate I and Intermediate II:

MODIFIED S. A. T. STRAND

THIS IS A SPECIAL TEST. YOU HAVE 38 MINUTES TO WORK ON IT. USE PENCIL AND PAPER TO WORK THE PROBLEMS.

ALL QUESTIONS ARE MULTIPLE CHOICE. TYPE A LETTER AND THEN THE RETURN KEY. USE THE RUBOUT KEY TO ERASE. USE THE RETURN KEY TO SKIP A PROBLEM.

HERE IS A SAMPLE PROBLEM.

4 + 9 =

A) 12
B) 5
C) 13
D) 49
E) NOT GIVEN
C

Figure 1. Instructions printed for the Primary II and for the Intermediate forms of the Modified Stanford Achievement Test (MSAT).

Choice of level of test. Choice of the level of the MSAT to be administered to a student is made with reference to his average GP in the math strands curriculum. This choice algorithm is presented in Table 7.

TABLE 7

Choice Algorithm on MSAT Test Level

Test Level	Range of average GP on date of administration
Primary II	2.0 - 3.5
Intermediate I	3.6 - 4.8
Intermediate II	4.9 - 6.5

Experiment I

The purpose of the experiment was to measure the effect of varying numbers of math strands sessions on arithmetic computation grade placement (GP) measured by the strands curriculum and by the MSAT. Each student was allowed to take only a specified number of math sessions at the terminal. All other sign ons were spent working language arts lessons.

Design. As many students as possible from among those who were taking both CAI math strands and CAI language arts, whose average GP on strands was between 2.4 and 5.9, and who had taken at least 15 math strands sessions, participated in the experiment. The students selected were assigned at random to five experimental groups that differ in the maximum number of math strands sessions they permitted during the experimental period of approximately five months.

Session limits were imposed on a calendar basis so that students with low numbers of sessions received them distributed throughout the experimental period. A participating student had no control over the type of lesson, math strands or language arts, he received. Whether he signed on for math strands or language arts a student was given a math strands lesson if he was eligible for one. Otherwise, he received a language arts lesson.

Eligibility for a math strands session was decided according to the following algorithm.

If

$$NS_i < \left[\left(\frac{TS_i}{TD_i} * D_i\right) + 2\right], \text{ where } TS_i \leq TD_i,$$

was true, then student i received a math strands session, otherwise, he received a language arts session. In the algorithm,

NS_i is the number of sessions taken during the experimental period by student i,

TS_i is total number of sessions student i is to receive during the experimental period,

TD_i is number of calendar days in the experimental period for student i,

D_i is number of calendar days student i has been in the experimental period,

and the brackets denote the next greatest integer. For example, suppose a student was in a 70 sessions group ($TS_i = 70$) and the experimental period was 150 days ($TD_i = 150$). If on the twenty-first day he was in the experiment ($D_i = 21$) he had taken 11 sessions ($NS_i = 11$), then he would receive a math strands session when he signed onto either math strands or language arts since

$$11 = NS_i < \left[\left(\frac{TS_i}{TD_i} * D_i\right) + 2\right] = \left[\left(\frac{70}{150} * 21\right) + 2\right] = 12 .$$

Some students signed on more than once a day in order to obtain the assigned number of sessions.

The actual number of math sessions a student received was monitored daily. The assistance of teachers and proctors was sought to help students achieve the number of math sessions they were assigned. Teachers were urged not to give compensatory off-line work to students assigned to low numbers of on-line sessions, and, in general, not to alter the classroom work of any student because of his participation in the experiment.

The MSAT was administered in January at the beginning of the experimental period and again in May immediately after the experiment ended.

One-way, fixed-effects analysis of variance was used to test for overall effect of treatment group. The model for this analysis is

$$Y_{ij} = \mu + a_j + e_{ij}$$

where Y_{ij} is posttreatment score for student i in treatment group j,

μ is overall mean,

a_j is effect of treatment group j,

e_{ij} is random error associated with student i in treatment j.

Both Y_{ij} and e_{ij} are assumed to be normally distributed, all treatment groups are assumed to have the same variance, and the errors associated with any pair of observations are assumed to be independent, i.e., $E(e_{ij}e_{k\ell}) = 0$ and $E(e_{ij}e_{kj}) = 0$ (Hays, 1963).

Additionally, it is important to investigate the relationship of posttreatment scores to pretreatment scores and the number of math strands sessions given. Five models of this relationship were tested. In all five models, T_{i1} denotes the pretreatment score of student i, T_{i2} denotes the posttreatment score of student i, and N_i denotes number of math strands sessions taken by student i.

Model I, Linear.

$$E(T_{i2}) = a_0 + a_1T_{i1} + a_2N_i .$$

In this model, the effect of pretreatment score and number of sessions on posttreatment performance is assumed to be linear.

Model II, Linear with interaction.

$$E(T_{i2}) = a_0 + a_1T_{i1} + a_2N_i + a_3T_{i1}N_i .$$

In Model II, a linear effect of pretreatment score and number of sessions is assumed, but a linear effect from the interaction of pretreatment score and sessions is also postulated.

Model III, Cobb-Douglas.

$$E(\ell n\, T_{i2}) = a_0 + a_1\, \ell n\, T_{i1} + a_2\, \ell n\, N_i .$$

Model III is based on a formulation of the Cobb-Douglas type (from econometrics), namely,

$$T_{i2} = a_0 T_{i1}^{a_1} N_i^{a_2} .$$

This model is multiplicative and assumes "weighted interaction" in that a_1 and a_2 indicate the relative importance of pretreatment score and number of sessions, respectively, in accounting for change in posttreatment scores.

Model IV, Log quadratic.

$$E(T_{i2}) = a_0 + a_1 T_{i1} + a_2 \ell n\, N_i + a_3 (\ell n\, N_i)^2 + a_4 (\ell n\, N_i)^3 .$$

In Model IV, the effect of the pretreatment score is assumed to be linear. The effect of number of sessions is assumed to be logarithmic, rather than linear. In order to explore this logarithmic assumption fully, second- and third-order terms in $\ell n\, N_i$ are included.

Model V, Exponential.

$$E(\ell n\, T_{i2}) = a_0 + a_1 N_i T_{i1} .$$

Model V is based on an exponential formulation, namely,

$$T_{i2} = a_0 e^{a_1 N_i T_{i1}} .$$

In this model, the effect of number of sessions and pretreatment score may be strictly increasing or strictly decreasing, depending on the sign of a_1. Pretreatment score and number of sessions are assumed to interact.

Complete data were obtained for 312 students and the results from Experiment I are discussed by Suppes, Fletcher, Zanotti, Lorton, and Searle (1972).

Experiment II

The purpose of Experiment II was to set a unique performance goal for each student and meet it by assigning the student more or fewer daily math strands sessions depending on his progress toward the goal. In the current version of the experiment, students are assigned either one or two sessions daily for a two-week period. At the end of the period, the students' progress is re-evaluated and re-assignments of daily sessions are made where necessary. Goals are defined in terms of average grade placement (GP) on the math strands program. At the end of the experiment, average strands GP achieved by each student is compared with his goal GP and with scores on external tests.

Design. Two performance goals were set for each student, one externally derived and one internally derived. The external goal was based on the amount of arithmetic GP gain deaf students are expected to achieve during a school year. The Experiment II period of 16 weeks was about one-half a school year, and the external goal GP was defined as

$$XGP_i = SGP_i + (.5 * EGP_i)$$

where XGP_i is external goal GP for student i,

SGP_i is start of experiment GP for student i,

EGP_i is expected gain in arithmetic GP on the SAT arithmetic computation subtest for the age group of which student i is a member.

Table 8 presents the expected change in arithmetic GP measured by the SAT arithmetic computation subtest for the three SAT forms used in Experiment II. Which form was relevant for a particular student depends on the MSAT form assigned to him by the algorithm presented in Table 7. If EGP_i for student i was less than .20, it was set to .20.

The internal goal GP was more individualized than the external goal GP in that it was derived from students' performance histories. In setting internal performance goals, GP change per session was obtained for each student for his 20th to 40th session. His goal GP was then determined by extrapolation from a model of his progress with parameters generated from these initial observations.

The six-week duration of Experiment II was divided into eight two-week periods starting on alternate Mondays. If pursued in the most straightforward manner, the experiment would assign all students to one session a day for the first two-week period, and, because of missed sessions, the high level of the internal goal GP, etc., would gradually assign more and more students to greater numbers of daily sessions in subsequent periods. The last experimental period might assign all students to the three daily sessions group. This manner of assignment would undoubtedly exasperate the participating schools as well as exaggerate whatever interaction might exist between number of daily sessions and rate of GP change. It was desirable, therefore, to extrapolate student progress over Experiment II with an adjustment for the probability that students would actually take an assigned session.

The following model was calculated for each student from the 20th-40th session observations:

$$GP_i = a_i + b_i S_i^c \qquad c \leq \tfrac{1}{3} \qquad (1)$$

TABLE 8

Grade Placement Changes as Measured by Stanford Achievement Test Arithmetic Computation Sub-Test (Gentile and DiFrancesca, 1969)

Primary II

Age	Gain
10-11 (gain)	+ .66
11-12 (loss)	- .15
12-13 (gain)	+ .28
13-14 (gain)	+ .11

Intermediate I

Age	Gain
12-13 (gain)	+ .35
13-14 (loss)	- .02
14-15 (gain)	+ .54
15-16 (loss)	- .05

Intermediate II

Age	Gain
13-14 (gain)	+ .89
14-15 (gain)	+ .20
15-16 (gain)	+ .26
16-17 (loss)	- .15

where GP_i is average GP for student i,

S_i is number of sessions completed by student i.

Extrapolation was accomplished by assigning a value to S_i and solving for GP_i. The value assigned to S_i was either the number of school days in Experiment II or some function of that number. The probability that student i would take an assigned session was initially estimated from the 20th to 40th session observations:

$$P_i(S) = \frac{ED_{i,s_1-s_2}}{OD_{i,s_1-s_2}} \qquad (2)$$

where $P_i(S)$ is the estimated probability that student i will receive an assigned session,

ED_{i,s_1-s_2} is the number of days student i was expected to require to take session s_1 to session s_2 inclusive.

OD_{i,s_1-s_2} is the number of days student i required to take sessions s_1 to s_2.

$P_i(S)$ was called a probability only for simplicity of conception. Clearly, if student i received more sessions than were assigned to him, $P_i(S)$ would be greater than 1.0. Also, the variance of the $P_i(S)$ is greater than desirable; a student may miss two weeks because of illness and not miss another school day for the rest of the school year. For this reason the $P_i(S)$ were used only for assigning numbers of daily sessions to students and not for setting goal GP's.

The number of sessions, S_i, required by student i to reach his goal GP calculated using S_i from the model (1) of his performance on strands was then adjusted by $P_i(S)$.

$$AS_i = S_i + ((1-P_i(S)) * S_i) \qquad (3)$$

where AS_i is the number of sessions required by student i to reach his goal GP adjusted by the probability that he will receive an assigned session.

S_i is the number of sessions student i is expected to take in the 16-week Experiment II period (this value is also used in the performance model (1) to determine the goal GP for student i),

$P_i(S)$ is the "probability" student i will actually receive an assigned session.

Number of sessions required daily of student i was defined as

$$NS_i = \frac{AS_i}{DL} \tag{4}$$

where NS_i is number of sessions required daily for student i,

AS_i is adjusted total number of sessions required by student i,

DL is number of days left in Experiment II.

Number of daily sessions, T_i, actually assigned to student i was defined as

$$T_i = \left\{ \begin{array}{ll} 1 & \text{if } 0 \leq NS_i \leq 1.0 \\ 2 & \text{otherwise} \end{array} \right\} \tag{5}$$

The procedures indicated by (2), (3), (4), and (5) were used for assigning students to one or two daily session treatment groups for the 16 two-week periods in Experiment II. The $P_i(S)$ were adjusted to include observations made during the experimental period as well as observations from the 20th to 40th session interval. Subsequent S_i used for calculating AS_i in (2) were the number of sessions students were expected to take in the time remaining for Experiment II.

A report was generated on alternate Wednesday nights and made available to the schools on the Thursday prior to the start of a new period. The Thursday report designated for the next period the assignment of Experiment II students to one of two groups, those who were to receive one or two math strands sessions daily, and the schools were expected to adjust the students' CAI schedule accordingly. The Thursday report, illustrated in Figure 2, contained the following information:

1) Student number.

2) Student name.

CLASS 303 MISS WALTER - 3D 20 APR 72
6 STUDENTS -- TEXAS SCHOOL FOR THE DEAF -- GRADE 8

NO. OF SES/DAY	TOTAL SES. AT END OF PERIOD	GOAL CHANGE	ACTUAL CHANGE	NUMBER	NAME
2	125	.690	.970	826	BARBARA DELGADO
3	110	.986	.660	828	KENNETH GOMEZ
2	127	1.150	1.420	830	ROBERTA NESBITT
3	112	1.150	.600	833	ALBERTO SANCHEZ

4 STUDENTS IN EXPERIMENT TWO

Figure 2. Illustration of the Thursday report: New assignments of number of daily sessions for next Experiment II period.

3) Assignment of the student to the one or two daily sessions group. This assignment accords with the definition of T_i described above.

4) Total number of sessions the student should have received at the end of the next period.

$$RS_i = CS_i + (CT_i * 2) + (T_i * DP)$$

where RS_i is number of sessions student i should have received at the end of the next period,

CS_i is current number of sessions student i has received,

CT_i is number of sessions student i is currently receiving daily (this value is multiplied by 2 to account for the fact that on Wednesday 2 days remain in the current period),

T_i is number of sessions student i is to receive daily during the next period,

DP is number of school days in the next two-week period.

5) Goal change, the change in average GP tenths the student should have achieved to accord with the model of his performance on strands used to determine his goal GP.

$$GC_i = (GP_i - SGP_i) * .10$$

where GP_i is grade placement for student i estimated under the assumptions and parameters used in (1),

SGP_i is the start of experiment GP for student i.

6) Actual change, the change in average GP tenths the student achieved during Experiment II.

$$AC_i = (CGP_i - SGP_i) * .10$$

where AC_i is change in GP observed for student i,

CGP_i is current GP for student i,

SGP_i is start of experiment GP for student i.

Data analysis. The proportion of students who reached the external goal and the proportion who reached the internal goal were determined. The distribution of errors about the internal goal was also determined; i.e., the distribution of the

$$(GP_i - GGP_i) ,$$

where GP_i is end of experiment grade placement for student i

GGP_i is goal grade placement for student i,

were determined. There was a good supply of students who undershot and overshot the internal goals. The mean, the variance, and the shape of the error distribution were all of interest.

An attempt was made to account for the trajectories of students' GP increases over time with a general rule. For simplicity of analysis these trajectories were assumed to be deterministic. A rule that accounts for all the individual trajectories, therefore, must be expressed in terms of rate of GP change, i.e., velocity, as

$$\frac{dg}{dt} = f_i'(t)$$

where $g = f_i(t)$ describes change in GP for student i as a function of time t; or in terms of rate of GP change, i.e., acceleration, as

$$\frac{d^2g}{dt^2} = f_i''(t) .$$

Five models of acceleration were examined.

Model I.

$$f_i''(t) = a_i .$$

Under Model I, acceleration is assumed to be constant for every student.

Model II.

$$f''_i(t) = a_i t .$$

Under Model II, acceleration is assumed to be a function of time. Also, acceleration at time zero (t = 0) is assumed to be zero, and the

student is assumed to be in a steady state with respect to GP change at the beginning of Experiment II.

Model III.

$$f_i''(t) = a_{1i} + a_{2i}t \ .$$

Under this model as under Model II, acceleration is assumed to be a function of time. However, at time zero, which is the beginning of Experiment II, acceleration is assumed to have some value different from zero.

Model IV.

$$f_i''(t) = a_1 e^{a_2 t} \ .$$

Under Model IV, acceleration is assumed to change exponentially as a function of time. As in Model III, acceleration is assumed to have a value other than zero at time zero.

Model V.

$$f''_i(t) = a_1(a_2-1)\ t^{a_2-2}, \qquad a_2 \leq 1 \ .$$

Under this model, acceleration is assumed to decrease monotonically as a function of time. If $a_2 = 0$, then $f_i''(t) = -\frac{a_1}{t^2}$ and, simply, $f_i(t) = a_1 \ln t + c$.

During 1971-72 the biweekly predictions in the experiment were made in terms of a linear model because the extensive analysis required to fit a more sophisticated model had not taken place. As reported in Suppes, Fletcher, and Zanotti (1972) models of the following form predicted student progress in Experiment II with a high degree of precision:

$$GP_i = a_i + b_i S_i^c, \qquad c \leq 1 \ ,$$

where GP_i is the grade placement of student i,

S_i is number of sessions taken by student i,

a_i and b_i are unique parameters of the model calculated for student i.

The two instances from this family of models used by Suppes, Fletcher, and Zanotti are the following

$$GP_i = a_i + b_i S_i^{1/3} \qquad (1)$$

$$GP_i = a_i + b_i \ell n(S_i) \qquad (2)$$

A graph of the first model with c = 1/3, the second logarithmic model, and progress actually observed for one student during the 1971-72 run of Experiment II is shown in Figure 3. Two aspects of these models are to be noted. First, they predict negative GP for low numbers of sessions; the exponential model (1) with c = 1/3 crosses the sessions axis (abscissa) between 0 and 1 sessions, and the logarithmic model (2) crosses the sessions axis between 4 and 5 sessions. The concept of negative GP is at least undefined and probably nonsensical. Second, it is not clear how to treat second, third, etc. year start-ups for a student whose progress has been observed and modeled before. The models used predict a scalloping effect if each year's progress is observed separately from progress in other years; i.e., in each year we would expect rapid initial progress that very gradually tapers off as the year wears on. If each new year's progress is treated as an extension of the previous year (i.e., the new sessions are simply added on to the previous total sessions), we can expect some imprecision to develop in the model.

For all the accuracy of the models in the 30-130 session range, we anticipate serious difficulties in predicting student progress for very small and very large numbers of sessions. Using the 1972-73 student data, we expect to make headway in solving these problems.

We do take it that the most important thrust of the evaluation of the mathematics curriculum will be the attempt in 1972-73 to build more adequate individualized models of student progress through the curriculum. If we can achieve at a reasonable level the objectives we have set of building a model with individual parameters for individual students, we believe that we will have taken a considerable step forward in being able to predict the progress of individual students. Our understanding of individual student progress will be superior to anything that is currently available either in computer-assisted instruction or in ordinary instruction.

Experiment III

Comparisons of the achievement measures used in this study with each other and with standardized tests are of natural interest. Generally, when an educator speaks of grade placement he has a standardized test in mind. Because neither the MSAT nor GP measured by the strands curriculum is a common measure, it was decided to estimate the concurrent validity

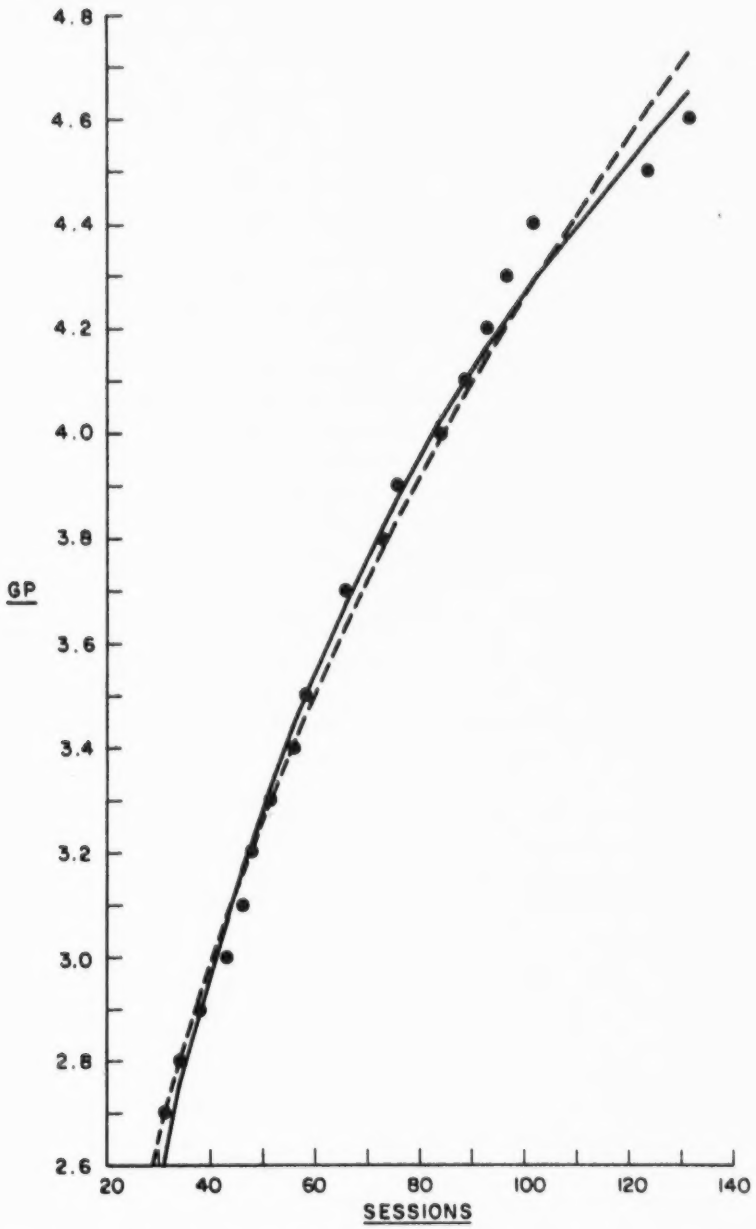

Figure 3. Graph of two models of predicted student progress and the progress actually observed for one student in the mathematics strands curriculum during 1971-72. The dashed line represents the exponential model:

$GP = - .573 + 1.042\ S^{1/3}$, where S is number of sessions taken.

The solid line represents the logarithmic model:

$$GP = - 2.203 + 1.404\ \ell n(S) .$$

The solid circles represent the progress actually observed for the student.

of the MSAT GP and strands average GP by comparing them with each other and with paper and pencil administrations of the SAT.

Design. Sixty subjects were drawn at random from among all subjects in three of the participating residential schools. Selection of the subjects was stratified so that four were chosen for each of the 15 MSAT form (Primary II, Intermediate I, Intermediate II) by treatment group (10, 40, 70, 100, 130 sessions) cells. Two of the four subjects were chosen at random and assigned to Group I, the remaining two were assigned to Group II. There were then 30 subjects (two from each form by treatment cell times 15 cells) assigned to Group I and 30 assigned to Group II. Group I received paper and pencil administration of the SAT Arithmetic Computation Subtest (SAT-COMP), Form W, before receiving the pretreatment MSAT, and Group II received the SAT-COMP after receiving the pretreatment MSAT. The roles of Group I and Group II were reversed for the posttreatment measure. Group II received the SAT-COMP before the posttreatment MSAT, and Group I received the SAT-COMP after the posttreatment MSAT. Pre- and posttreatment strands GP scores were also recorded for all the subjects.

Complete data were obtained for 44 of these subjects. The loss of 16 subjects was solely due to such random factors as student illness, change of schools, administration errors. Means and standard deviations obtained by the 44 subjects for pre- and posttreatment SAT GP, MSAT GP, and strands GP are displayed in Table 9. It should be noted from Table 9 that the SAT consistently gives the highest estimate of GP for this group of students, the MSAT consistently gives the second highest GP estimate, and the strands GP consistently gives the lowest GP estimate. In other words, both the MSAT and the strands average GP measures underestimate GP measured by paper and pencil administration of the SAT.

A matrix of simple correlations for the GP scores obtained by the 44 subjects on pre- and posttreatment SAT, MSAT, and math strands is given in Table 10. These correlations are fairly large, but they are not sufficiently large to identify SAT GP, MSAT GP, and strands GP as parallel measures. According to Lord and Novick (1968), two distinct measurements X_{ga} and X_{ha} are parallel if for every subject, a, in the population, $\pi_{ga} = \pi_{ha}$ and $\sigma(E_{ga}) = \sigma(E_{ha})$, where π indicates measurements with the same true scores but possibly different error variances. More intuitively, two measurements are parallel if their expectations are equivalent and their observed score variances are equal. This is not true of the three GP measures.

The correlations of posttreatment SAT GP with posttreatment MSAT GP and of posttreatment SAT GP with post-treatment strands GP would be higher if the modeled relationships were not curved. Examination of the scatter plots obtained from the 44 students' GP scores indicates a linear relation between the lower SAT GP scores and the lower MSAT GP scores and between the lower SAT GP scores and the lower strands GP scores, but for higher GP scores the tendency for both MSAT GP and strands GP to underestimate SAT GP gradually increases.

TABLE 9

Means and Standard Deviations Obtained by 44 Randomly Chosen Students for Pre- and Posttreatment SAT Grade Placement, MSAT Grade Placement, and Math Strands Average Grade Placement

	SAT GP pretreatment	SAT GP posttreatment	MSAT GP pretreatment	MSAT GP posttreatment	Strands GP pretreatment	Strands GP posttreatment
Mean	5.01	5.69	4.88	5.24	4.27	4.84
Standard deviation	1.13	1.40	1.53	1.46	.91	.96

TABLE 10

Matrix of Simple Correlation Coefficients for Grade Placement Scores Obtained by 44 Randomly Chosen Students on Pre- and Posttreatment SAT, MSAT, and Math Strands Observations

	SAT pre-treatment	SAT post-treatment	MSAT pre-treatment	MSAT post-treatment	Strands pre-treatment	Strands post-treatment
SAT pre-treatment	1.000	.761	.787	.689	.685	.733
SAT post-treatment		1.000	.773	.827	.758	.794
MSAT pre-treatment			1.000	.833	.800	.796
MSAT post-treatment				1.000	.764	.807
Strands pre-treatment					1.000	.860
Strands post-treatment						1.000

A more complete discussion of Experiment III is given by Suppes, Fletcher, Zanotti, Lorton, and Searle (1972).

Conclusions

As reported by Suppes, Fletcher, Zanotti, Lorton, and Searle (1972), analysis of variance indicated a significant effect ($F = 9.088$, $df = 4,307$, $p < .01$) for number of math strands CAI sessions on the average GP measured by the strands program and a nonsignificant effect ($F = 1.464$, $df = 4,307$) for number of sessions on MSAT GP. In both the 44-subject sample and the full 312-subject population, MSAT GP appeared less sensitive to different numbers of CAI sessions than did strands average GP. In the 312-subject population the correlation for number of sessions taken and MSAT GP was .155 compared with .416 for number of sessions and strands GP.

Means and standard deviations for GP change (posttreatment GP minus pretreatment GP) obtained by the five treatment groups are displayed in Table 11. With the exception of average GP change for Group 3, a fairly steady increase in GP change with increasing number of sessions is evident in the data. It should be noted that the GP change for Group 5 whose members averaged 75.84 sessions is .96 for strands average GP and .76 for MSAT GP. Both of these measures underestimated GP measured by paper and pencil administration of the SAT to the 44-subject sample. In the worst case, the Group 5 students achieved an increase in mathematics computation GP of .76 during the experimental period of approximately five months. This improvement is about double the GP gain indicated by Gentile and DiFrancesca (1969) for hearing-impaired students after an entire school year of traditional classroom instruction.

That we can expect a fairly dramatic improvement in mathematics computation GP is supported by an examination of the models of student achievement. The simple, linear model of achievement, measured by strands average GP, as a function of pretreatment GP (T_{i1}) and number of sessions taken (N_i) is, from Suppes, et al.,

$$T_{i2} = .305 + .930\ T_{i1} + .012\ N_i ,$$

where T_{i2} is the posttreatment strands GP. This model accounts for 91 percent of the variance in the posttreatment distribution of GP scores and projects an improvement of 1.48 in GP over a school year assuming 120 sessions, or less than one 10-minute CAI session per school day. This improvement is about four times what the Gentile and DiFrancesca (1969) survey indicates for hearing-impaired students, and we iterate that this improvement underestimated GP measured by paper and pencil administrations of the SAT.

The ability of the simple, linear model of student achievement to account for posttreatment distribution GP measured by the MSAT and by the strands curriculum is worth noting. Very little improvement in accounting for posttreatment GP variance is achieved by the addition of interaction

TABLE 11

Sample Size, Mean, and Standard Deviation of GP Change (Posttreatment GP Minus Pretreatment GP) Measured by Strands Average GP and MSAT GP for the Five Treatment Groups

	Treatment group	1	2	3	4	5
	Sample size	60	62	60	60	70
Strands Δ GP	Mean	.15	.45	.64	.91	.96
	Standard deviation	.01	.03	.03	.05	.05
MSAT Δ GP	Mean	.42	.58	.48	.68	.76
	Standard deviation	.10	.09	.08	.10	.11

terms to these models. Greater numbers of CAI sessions seem to be equally beneficial for all students, across all levels of pretreatment ability. The inequality averting properties of the math strands curriculum used as compensatory education for hearing students has already been noted by Jamison, Fletcher, Suppes, and Atkinson (1972). These properties seem to obtain equally well for the population of hearing-impaired students used in this study.

We conclude, then, that the mathematics strands CAI curriculum can achieve fairly dramatic increases in mathematics computation GP and, concomitantly, in computation ability when used by hearing-impaired students. Further, these increases occur equally across all levels of ability. That students enjoy CAI, that it provides immediate knowledge of results, that it is absolutely impartial in evaluating student responses, and that its benefits are easily replicable independent of the enthusiasm and ability of educators typically associated with pilot projects have all been noted and emphasized elsewhere. The studies reported here indicate the impact CAI can have when properly applied in a large-scale project.

Language Arts Curriculum for Hearing Impaired Students

Introduction

The effort in the Language Arts program has been to develop a computer-assisted instruction (CAI) curriculum in standard English usage and a related paper and pencil test for students between the ages of 12 and 16 enrolled in special schools or classes for the deaf and hard of hearing. Rawlings' survey (1971) indicates that 74 percent of the students in these schools and classes have suffered a hearing loss of 60 decibels or more in the better ear. Mean grade placement (GP) reading levels measured by the Stanford Achievement Test (SAT) for hearing impaired students 12 to 16 years of age are given in Table 12.

A vocabulary list was generated for the curriculum by taking the words common to the third-grade vocabulary lists of four widely used basal readers: Scott-Foresman (1962), Lippincott (1964), Ginn (1966), and Macmillan (1966). Although words not found in this list are occasionally used in the Language Arts course, an attempt was made to restrict the vocabulary to this list. The list is given in Appendix A. A Dictionary of Idioms for the Deaf (Boatner and Gates, 1966) was also consulted in determining the vocabulary for the course. Teachers in the participating schools emphasized that idioms are confusing to their students, and an attempt was made to avoid idiomatic constructions in the course.

Most language curriculums in schools and classes for the hearing impaired are based on the Fitzgerald Key (Fitzgerald, 1949). This system classifies all words and phrases into categories identified by such words as "who," "what," "where," and "when." Deaf students are taught standard English usage by identifying the Fitzgerald category to which

TABLE 12

Total Reading Grade Equivalencies for Students with a Hearing Loss Threshold of 60 Decibels and Above (Gentile and DiFrancesca, 1969)

	12	13	14	15	16
Primary II	2.41	2.51	2.44		
Intermediate I	3.41	3.46	3.33	3.33	3.35
Intermediate II		3.97	4.31	4.24	4.17

words in question belong. The teacher is to focus on words suggested by objects in the room or experiences of the students. Because this method depends heavily on classroom experiences and because consultants called in to aid in the design of the curriculum recommended a fresh approach, the Fitzgerald Key is used only sparingly in the CAI curriculum.

The basic problem in teaching English to hearing impaired students is that they have little or no aural language on which to build. Unlike a hearing student, the hearing impaired student is unlikely to have internalized much English syntax, inflection, or vocabulary before he starts school. Rawlings' survey (1971) indicates that 75 percent of students in special classes for the hearing impaired experienced hearing loss before age three. There is a real possibility that the deaf child can never assimilate the basic principles of English that a hearing child acquires at an early age (Lenneberg, 1967). For a deaf child, learning to read is more than a grapheme to phoneme decoding task; it is actually learning a language from its written form. Learning to write standard English is similarly complicated for a deaf student.

The language difficulties of hearing impaired students were carefully considered in developing the Language Arts curriculum. The curriculum was designed to stress the structure of English, with particular emphasis on the roles of syntax and inflection and on the meaning of function words. Later, the teaching strategy of the course will be discussed in more detail, but there are some ways in which that strategy partially determines the content of the course. An inductive rather than a deductive strategy is used. Therefore, the grammar course does not explicitly state "rules" of English usage, but instead presents items illustrating aspects of standard English usage singly and in combination. Incidental learning of basic sentence patterns is enhanced by presenting curriculum items in complete sentences. Fewer than one-tenth of the exercises present the student with single words or isolated phrases. Incidental learning is also enhanced by requiring many constructed rather than multiple-choice responses.

The course is not intended to be a complete course in English. Classroom instruction remains the largest portion of the student's language experience, while the CAI course provides supplementary, individualized drill. The classroom schedule of instruction need not be altered to adapt to the sequence of instruction in the CAI course, although paper-and-pencil drill given in the classroom can be reduced. No specific instruction in standard English usage is needed before students begin this course.

Description of the Language Arts Curriculum

The curriculum is divided into 218 lessons of 20-30 exercises. It is designed to provide a student for whom the course is intended with 10 minutes of daily drill and practice for an entire school year. An outline of the course is included as Appendix B. Separate topics are presented in separate lessons and often there is a sequence of lessons on a single topic. The lessons are ordered to provide a cumulative basis

of concepts building upon one another. Several lessons are intended to review topics presented in preceding lessons.

If a lesson introduces a new topic, carefully sequenced explanation and instruction are given in a short "tutorial" section at the beginning of the lesson. In subsequent lessons on the same subject, short but complete instructions are given. The inclusion of this tutorial instruction allows students to proceed through the course at their own pace, without waiting for group instruction on each new topic.

To provide for further individualization of instruction, each lesson contains one or more "checkpoints." At these points the student's performance on the lesson is graded, and a decision is made to give him more practice or allow him to skip to the next lesson. This checking is done automatically by the computer program and usually occurs after the sixth or seventh exercise in the lesson. In most cases the student must achieve a fairly high performance level, for example, 85 percent correct or better, before he is allowed to skip the lesson.

The order in which the lessons are given in the outline is the order in which most students encounter them. The lessons are interrelated in that concepts introduced in earlier lessons are used to explain concepts introduced in later lessons. However, lessons can be taken out of sequence. Each lesson is self-contained in that the task is completely explained and, except for the mixed drill lessons, each lesson focuses on a specifically defined task. A teacher can easily alter the order in which the students encounter lessons to conform more closely with the development of classroom work, or to provide certain students with review lessons on a specific topic.

Suggestions for the curriculum content came from many sources. One of the most important of these was the Kendall School for the Deaf in Washington, D.C. Stanford and Kendall staff members worked together during the spring and summer of 1970 to develop programmed lessons in English usage for students at the school. This was part of a larger Kendall plan to develop curriculum material in transformational grammar for deaf students. To some extent, the content of the Language Arts Course was determined by this early cooperation; many parts of the current curriculum reflect an orientation toward transformational grammar, though more traditional approaches to teaching standard usage are also included. Many helpful ideas were drawn from The Roberts English Series (Roberts, Ross, and Boyd, 1970), and the workbooks for the series furnished examples for specific items.

In addition, teachers from the schools whose students used the course have been encouraged to contribute ideas and criticism. In some cases, these suggestions have resulted directly in the writing of a series of lessons; these comments on early lessons provided a helpful framework for planning and writing subsequent lessons.

Finally, samples of written work by students at Kendall School and California School for the Deaf at Berkeley were studied to indicate problem areas peculiar to deaf students. Neither the volume nor the breadth of this early corpus was sufficient to justify detailed statistical study; however, the nature of the errors observed in the students' work confirmed previous tentative conclusions regarding course content. Further samples of spontaneous written language of deaf students have been gathered from the schools and from the TALK program developed at IMSSS. These samples are now being more thoroughly analyzed.

Terminology used in the Language Arts Course reflects the blend of transformational and traditional approaches mentioned above. To some extent, it uses the terminology found in the Roberts series through the 4th grade, and these terms are not substantially different from those used in other curriculums reviewed by the Stanford staff. Some greater degree of precision is afforded by use of the Roberts terms in a few cases; e.g., the common term "auxiliary" is not used because understanding the function of elements commonly called auxiliaries in the phrases presented by the curriculum requires a set of more precise terms, so, for instance, the term "modal" is used to identify constituents such as can, may, will, etc. In addition to terms taken from other language curriculums, some labels were invented specifically for the Language Arts Course to keep the terminology as short and clear as possible. Thus, for example, "ing-form" is used instead of "present participle," "have-word" for "form of the verb have," "not-sentence" for "negative sentence."

An underlying goal of the Language Arts Course is to focus attention on groups of words performing a single function, rather than on individual words alone. This goal explains the great emphasis on noun, prepositions, and verb phrases; all work on specific constituents of these phrases leads directly to work involving the group of words functioning in the sentence. Emphasis is also given to agreement between parts of phrases and agreement between parts of the sentence.

Course objectives. There are four general course objectives. Students are to:

(1) Recognize specified grammatical categories;

(2) Recognize and supply various forms of given grammatical structures;

(3) Select appropriate grammatical units to complete a specified structure; and

(4) Perform specified transformations on grammatical structures.

Under objective (1) the following parts of speech and grammatical structures are explicitly identified: noun, determiner, noun phrase, verb, adjective, subject, predicate, pronoun, modal, vowel, preposition, prepositional phrase, and contraction. The student should be able to

recognize the structure and identify the structure in a sentence. The specific tasks are:

(a) Identify one or more nouns, in either a nominative or objective position.

(b) Identify one or more of the following as determiners "a," "an," "the," "some," "every," "no," "all," cardinal numbers from "one" to "ten," and double determiners with "all" or cardinals.

(c) Identify isolated vowels, and select from a group of words the one that starts with a vowel.

(d) Identify noun phrases (appearing in either a nominative or objective position) of the following types: single noun or pronoun, determiner-noun, determiner-adjective-noun, determiner-determiner-noun, adjective-noun, determiner-adjective-adjective-noun. Noun phrases are ordinally specified, specified as singular or plural, or specified as possessive.

(e) Select from a given sentence one or more nouns specified as singular or plural.

(f) Identify verbs in the simple present, present progressive, simple past, past progressive, modal form, or "be-word" form.

(g) Identify from a given sentence one or more nominative or predicate adjectives.

(h) Identify the complete subject (either simple or compound) and the complete predicate of a given sentence and indicate whether the subject is singular or plural.

(i) Identify as pronouns: "he," "she," "it," "they," "I," "you," "we," "me," "him," "her," "us," and "them"; and as possessive pronouns: "my," "his," "her," "its," "your," "our," and "their."

(j) Identify as prepositions: "in," "to," "of," "for," "with," "on," "at," "by," "from," "after," "into," "over," "before."

(k) Identify prepositional phrases of the following types: preposition-noun, preposition-determiner-noun, preposition-adjective-noun, preposition-determiner-adjective-noun. Prepositional phrases are ordinally specified or specified as a phrase that tells "where" or "when."

(l) Identify contractions with forms of "be" and negative contractions with forms of "have," "be," and "do."

(m) Given a declarative sentence and a related question, identify the nominative or objective noun phrase or the prepositional phrase that answers the question.

Under objective (2) the student should be able to:

(a) Supply the plurals of given singular nouns, and the singulars of given plural nouns, both regular and irregular. Regular nouns include those whose plurals are formed by adding -s, -es, (y)-ies, or (f)-ves. Irregular nouns given are: "man," "woman," "child," "foot," "mouse," "sheep," "deer," "aspirin," and "offspring."

(b) Indicate whether a specified noun phrase is singular or plural.

(c) Given the root form of a verb, supply the gender marked form (third person singular), simple past, or present participle. Verbs given are regular (including those ending with single consonants and -y) and the irregular verbs "have," "go," and "do" in the third person singular and past forms.

Under objective (3) the student should be able to:

(a) Type "a" or "an" before a given noun in a sentence, depending on the first letter of the noun.

(b) Choose from two given determiners the one that agrees in number with a given singular or plural noun in a sentence.

(c) Choose from two given pronouns the one that is appropriate either in number or gender or case or all three for the noun phrase that it will replace.

(d) Choose among given prepositions the one that is appropriate to complete a sentence, or given a parallel sentence, type the correct preposition to complete a sentence.

(e) Choose the correct inflection of a verb based on subject-verb agreement in number.

(f) Choose the correct noun form or pronoun based on subject-verb agreement in number.

(g) Given the root form of a verb, construct the correct form of the present progressive to complete a sentence.

Under objective (4) the student should be able to:

(a) Combine two related sentences into one by specifying the position of an adjective to be inserted.

(b) Indicate the negative transform of a given sentence (including a modal, a form of "have," or a form of "be") by specifying the position of "not."

(c) Indicate the question transform of a sentence by choosing the modal, have-word, or be-word that changes position.

(d) Construct a possessive noun phrase from a sentence of the form: noun phrase, form of "have," noun phrase.

(e) Make a contraction of "be" and a pronoun or noun phrase.

(f) Expand a contraction with "be" and a pronoun or noun phrase.

(g) Make a negative contraction of "be," "have," or "do."

(h) Expand a negative contraction of "be," "have," or "do."

The course begins with 10 introductory lessons. The first lesson familiarizes the student with the teletype with specific attention to potential sources of confusion such as the number 1 and the letter I, and the number zero and the letter O. The nine "directions" lessons which follow the first introductory lesson serve two purposes: (1) they provide material requested in early consultations by some teachers of deaf students, and (2) they familiarize the student further with the different kinds of instructions he will encounter later throughout the course. These lessons are parallel to, but not as extensive as, The Language of Directions by Mary Lou Rush (1970).

The specific objectives of the directions lessons are that students should be able to do the following:

(a) Type any letter or letters in a given word identified by one of the following: ordinals ("first" through "fourth"), "after the first," "first two," "last," "before the last," "last two."

(b) Type any word or words in a given sentence identified by one of the following: ordinals ("first" through "fourth"), "after" or "before" a given word, "before the last."

(c) Copy on the teletype a two- or three-word phrase from a given sentence, including the space between words.

(d) Given two or three rows of numbers (each row containing up to five numbers), type any number whose position is specified by "above," "below," or "under" another number.

Exercise tasks. Each exercise or curriculum item involves three steps: read the instructions or have them in mind when instructions for similar exercises have not been repeated; determine the answer; type the answer. One categorization of the exercise tasks accords with the first

step, reading or remembering the instructions. Under this scheme there are four basic exercise tasks, the last two of which are simple variants of the first two.

The first of these tasks is labeled recognition. In this task, the correct response is printed somewhere in the exercise display that is given to the student before he is required to respond. If the student can recognize the correct answer, he need only copy it. The following are two examples of this task:

// TYPE THE NOUN.

The dog is sleeping.

// TYPE "A" OR "AN."

An airplane has --- engine.

The second of these exercise tasks is labeled construction. These tasks require the construction of a word or phrase not printed in the exercise display. Two examples of construction tasks are the following:

// TYPE THE NOUN.

Woman

// MAKE A POSSESSIVE NOUN PHRASE.

They have a football.

The third and fourth exercise tasks are labeled recognition without instruction and construction without instruction. They differ from the first two tasks only in that the instructions for them are not printed in the exercise display. They occur in lessons in which all the exercises require equivalent instructions. In general, the instructions are not repeated after the third or fourth exercise in these lessons.

A second categorization of the exercise tasks expands the first four-member categorization scheme into 19 members. This second categorization has more cognitive overtones than the first, but, still, it is unambiguously based on the instructions given to the students. There are four dimensions of this categorization:

(a) Instructions given or no instructions given. As before, this dimension distinguishes exercises that occur early for which the instructions are printed or repeated, from exercises that occur later in lessons when it can be assumed the student has them well in mind and they do not require repetition.

(b) Instance (number) or instance (text) or concept. This dimension distinguishes exercises in which the student must answer with an instance of a concept from exercises in which the student must answer with a concept based on a given instance. When concepts are to be given as answers they are always abbreviated. The instances may be numbered so the student need reply only with the number(s) associated with the text of the instance--instance (number)--rather than having to type the actual text of the instances--instance (text).

(c) Recognition or construction (explicit basis) or construction (implicit basis). As in the first categorization of exercise tasks, this dimension distinguishes exercises in which the answer is printed in the exercise display--recognition--from exercises in which the answer does not appear in the display--construction. The construction (explicit basis) and construction (implicit basis) dimensions distinguish between degrees of explicitness in the exercise directions. In construction (explicit basis) a form, but not the correct form, of the correct answer text is given; in construction (implicit basis) no form of the correct answer is given explicitly.

(d) Usage or definition. This dimension distinguishes exercises in which the answer is to be derived on the basis of an implicit rule of usage taught inductively in the curriculum from exercises in which the answer is to be derived from the definition of a grammatical category.

Given 2 times 3 times 3 times 2 possibilities, there would be 36 categories under this task classification scheme if it were not for the following combinations that do not occur:

there are no concept - construction tasks;
there are no concept - usage tasks;
and there are no instance (number) - construction tasks.

Eighteen categories are left plus one category labeled "Giveaway." The Giveaway category and nine of the 18 categories with one example for each follow. The nine excluded categories are simply those from the no instruction dimension, i.e., the categories not listed and exemplified would be exactly the same as those listed except the instructions would be withheld.

(1) Instance (number) - recognition - usage.

// WHERE DOES THE ADJECTIVE GO?

// TYPE A NUMBER.

The ten men lifted weights.

1 2 3 4 5 6

(The men were strong.)

(2) Instance (number) - recognition - definition.

// TYPE THE NUMBERS UNDER THE SUBJECT.

Some little boys can swim fast.
1 2 3 4 5 6

(3) Instance (text) - recognition - usage.

// TYPE "IT" OR "THEY" TO COMPLETE THE SENTENCE.

The little apples were sour.

--- were sour.

(4) Instance (text) - recognition - definition.

// TYPE THE NOUN.

Our school is new.

(5) Instance (text) - construction (implicit basis) - usage.

// COMPLETE THE SECOND SENTENCE.

My sister goes downtown for the parade.

The babies --- downtown with her.

(6) Instance (text) - construction (implicit basis) - definition.

// MAKE A POSSESSIVE NOUN PHRASE.

The boy has a dog.

(7) Instance (text) - construction (explicit basis) - usage.

// TYPE THE PRESENT PROGRESSIVE OF "COOK."

Tonight my father --- for us.

(8) Instance (text) - construction (explicit basis) - definition.

// TYPE THE PLURAL.

Wife

(9) Concept - recognition - definition.

// TYPE "NP" OR "ADJ" OR "V."

Some bicycles were red.

(10) Giveaway.

// CHANGE THE NEGATIVE CONTRACTION.

The apple isn't ripe yet.

// YOU SHOULD TYPE "IS NOT."

A third categorization of the exercise task is based solely on the format of the correct answer. The two dimensions of this categorization are the following.

a) Word or letter or number or abbreviation. There is some "nesting" under this dimension: word is subclassified as 1, 2, 3, or 4 word strings; letter is classified as 1, 2, or 3 letter strings; and number is classified as 1, 2, 3, 4, or 5 number strings. Abbreviations present a problem in that they could reasonably be classified as single letters, multiple letters, or single words. It was decided that they would confuse the single letter, multiple letter, or single word results, and they will be treated separately in the exercise task data analyses.

b) Sequence or no sequence. In some instances, the sequence of a multiple word, multiple letter, or multiple number response is important; in some instances sequence is not important. This dimension is intended to distinguish between these instances.

The 17 tasks under this third categorization scheme that actually occur in the curriculum are the following.

(1) Single word.
(2) Two words - no sequence.
(3) Three words - no sequence.
(4) Single letter.
(5) Two letters - no sequence.
(6) Three letters - no sequence.
(7) Single number.
(8) Two numbers - no sequence.
(9) Three numbers - no sequence.
(10) Abbreviation.
(11) Two words - sequence.
(12) Three words - sequence.
(13) Four words - sequence

(14) Two numbers - sequence.

(15) Three numbers - sequence.

(16) Four numbers - sequence.

(17) Five numbers - sequence.

All exercises in the curriculum have been labeled with respect to each of the three exercise task categorization procedures. In the evaluation of the curriculum, comparisons among categories and stepwise multivariate regression will be used to determine if the difficulty of an item is to some significant extent attributable to the exercise task it represents.

Teaching strategies. It is important in any discussion of CAI to understand the freedoms and limitations of the medium. One feature common to all IMSSS CAI courses is some individualization in the sequence and content of the instruction. Curriculum is generally aimed at satisfying a range of student needs and student abilities. CAI allows for individualized instruction by tailoring curriculums for each student on the basis of his response history. Further, CAI allows each student to work alone in an environment which need not be as competitive, threatening, or judgmental as the classroom.

IMSSS CAI curriculums do not depend on the presence of a knowledgeable teacher to help the student work at the computer terminal. The courses are self-contained, and must supply as many appropriate explanations and alternative examples as possible.

The Language Arts Course is a unique curriculum. Though its content is not remarkably different from other language study courses for hearing impaired students, its method is by necessity significantly different. Its design includes: (1) consistency of format, (2) unambiguity of "correct" answers, (3) specific correction messages appropriate to incorrect responses, (4) internal data collection, (5) branching around blocks of material for more able students, and (6) choice mechanism, allowing a variety of lessons.

Formats of instructions are consistent and unambiguous. The student is always allowed the options of having the problem repeated, frequently with a "help" message further clarifying the task, or of requesting the correct answer to any problem. Instructions are as short as possible, and the nature of the task is the same throughout a lesson.

Our ability to measure degrees of correctness objectively is limited. Thus, the course is planned to avoid any ambiguity in the choice of correct answers. In a lesson with tasks that might lead to ambiguity, the first few problems give extra help to the student, allowing him to see a pattern and then follow it on his own throughout the lesson. The course does not list rules of English usage; rather, it illustrates particular patterns of English and provides drill for the student to develop his own understanding.

Students taking the course may receive appropriate correction for their particular wrong responses. For almost every exercise throughout the course, careful attention has been given to a variety of likely wrong answers. Short but helpful messages, explaining the nature of the error, are returned immediately after a particular wrong response. An attempt is made at all times to reinforce any response which contains a part of the correct answer and to lead the student to the complete correct answer.

CAI differs from ordinary classroom instruction particularly in the ability to store complete response data. This ability qualifies it as a research tool as well as a teaching medium. Precise information on each student's response is stored for later analysis and revision of the course. Daily reports are written and may be listed by teachers and the IMSSS staff to monitor students' progress and lesson scores.

In all lessons except the review tests and the first introductory lesson, a student who demonstrates his ability to perform the task required early in the lesson is automatically branched to the next lesson. This is accomplished by a checkpoint after 6-9 items, requiring 85 percent correct responses on the first attempt to execute the branch. He is allowed to miss one problem, but not two or more, in order to branch ahead. In the "directions" lessons at the beginning of the course, scores are checked more frequently, allowing a student who has mastered the task by the middle of the lesson to bypass the rest. This branching scheme allows a student who is proficient on one topic to branch ahead to an area with which he may be less familiar.

The Language Arts Course is intended to be a flexible set of lessons. Although the order of topics is mixed, lesson names give an idea of the content of each. A teacher who chooses to vary the order of presentation, or to give a particular student further work in a particular topic, need only consult a brief outline, type a special command, and tell the program which lesson is desired. This allows for considerable flexibility to the teacher who wishes to use it. If teachers do not wish to take responsibility for this part of the language teaching, they may leave it to the CAI course and allow students to follow the established sequence.

Reports. The Language Arts Course collects complete data on each student's responses. This data is categorized and made available in reports summarizing various aspects of course usage.

A daily report program makes available detailed information on student progress. The report gives information by IMSSS class number and is available both to teachers in the participating schools and to the IMSSS staff. An example of a daily report is shown in Figure 4. The report heading documents the class number, teacher's name, date of the report, number of students in the class (including those not flagged for the grammar course), name of the school, and class grade. The first number in the row of student information is the total number of lessons the student has completed to date. The number following that in parentheses

CLASS 542 MR. RAPHAEL 10 APR 72
9 STUDENTS -- VICTORIA SCHOOL - HOUSTON -- GRADE 5

LANGUAGE ARTS (G) REPORT

57(5) LESSONS 40/41 = 97% 19.1 MIN + 2834 JERRY HOPKINS
DAD 23/26 MAE 7/ 7 NPAC 7/ 8 DAE 7/ 7
DAF 3/ 7 DAG (CONT)

23 TOTAL LESSONS 2837 MATT ARNOLD

2 TOTAL LESSONS 2950 BILL MORRIS

Figure 4. Illustration of Language Arts Curriculum daily report.

is the number of lessons completed on that day. After the word 'LESSONS', the program prints the total score for the day (number of correct responses/number of completed problems) and converts the score to a percentage correct. The number of problems includes all problems completed on that day, not just the problems in the completed lessons. Following the percentage score is the total number of minutes the student has accumulated in the curriculum, a plus sign if the student used the course on the date of the report, the student's number and his name. On the second and following lines, the report lists the names of lessons the student completed on the day of the report, giving a score for each lesson (number of correct responses/number of completed problems). If the student stopped in the middle of a lesson, that lesson is listed but the score will not be reported. Exercises completed in unfinished lessons will be added to the daily totals reported on the first line. If the student has not taken a lesson on the date of the report, only his number, name, and total lessons completed will appear.

Another report is available that gives for each student all the lessons completed to date by name and includes number of problems taken, percentage correct for each lesson, and an ordinal to indicate the order in which the lesson was taken. This report is not available "on-line" as is the daily report, but it is prepared and sent to teachers upon request. An example of this report is given in Figure 5. The report is generated by scanning the stored student response data for a given class of students over a given period of time. The class number and period scanned are given in the heading.

The IMSSS Language Arts Test

During the spring of 1971 an extensive search was made for a paper and pencil language test that would measure understanding of the language concepts covered in the Language Arts for the Deaf course. Few language tests were found which were at all suitable for deaf students; none were suitable for the CAI curriculum. The Full-Range Picture Vocabulary Test (Ammons and Ammons, 1948) and the Peabody Picture Vocabulary Test (Dunn, 1959) are both fairly widely used in schools for the deaf but they test receptive rather than expressive language and they emphasize word meaning rather than word usage. The Illinois Communication Scale (Withrow, 1966) also tests receptive rather than expressive language and the fact that it requires film makes it expensive and complicated to administer. The Language Test part of the Tests of Basic Experiences (Moss, 1970) also tests receptive rather than expressive language, only about 30 items test word usage as opposed to word meaning. Language Skills for Americans (Stillwagon and Leake, 1952), the Language Facility Test (Daily, 1968), and the Language Usage Test developed at the Clarke School for the Deaf all test usage, punctuation, capitalization, and spelling. Only a small number of items in these three tests cover the same topics that are covered by the CAI Language Arts course and many of the items are too difficult for the CAI students. The Gates-MacGintie Reading Tests (Gates and MacGintie, 1965), the Lee-Clark Reading Test (Lee and Clark, 1958), Primary Reading Profiles (Stroud, Hieronymus,

class 401		10-26-1971 thru 12-17-1971				student 460			Joyce Carey		
DAH			VAA	7	100%	VAB	7	100%	MAF	7	85%
VAC	7	100%	VAD	7	85%	MAG	8	100%	TC	19	78%
VAE	28	57%	AJAA	7	85%	AJAB	7	100%	AJAC	23	69%
MAH	28	85%	MAI	27	77%	NPAD	22	77%	NPAE	25	72%
NPAF	21	57%	AJAD	20	65%	MAJ	21	76%	MAK		

class 401		10-26-1971 thru 12-17-1971				student 461			Gully Jimpson		
INTRO	28	85%	DIR	21	61%	DIR2	7	100%	DIR3		

Figure 5. Example of the off-line Language Arts report for two students in class 401. The period scanned was October 26, 1971 to December 17, 1971. The entry for each lesson consists of lesson name, number of exercises completed in the lesson, and percentage correct.

and McKee, 1957), the Kansas Primary Reading Test (Schrammel. Hoag, Humble, Robinson and Wipf, 1935), and the Newstime Diagnostic Reading Test (1963) all test word recognition and reading comprehension rather than standard English usage. The language test developed at the California School for the Deaf at Berkeley (Marshall, 1952), the tests developed as part of the language curriculum, Generating English Sentences (Stokoe, Goldberg, Covington, LaRue, Womeldorf, and Bornstein, 1967), and the language tests developed at the Lexington School for the deaf (Cooper, 1965) all call for constructed answers and provide no precise guidelines for correcting the test. The Picture Story Language Test (Myklebust, 1965) covers many of the same aspects of usage that are covered in the Language Arts curriculum, but the complexity of scoring this test makes it impractical for a large number of students. The Illinois Test of Psycholinguistic Ability (McCarthy and Kirk, 1963) is used in several schools for the deaf and many teachers consider it a valuable diagnostic tool. Because it can only be administered individually, however, it would be impractical for testing all of the students working on the CAI curriculum. The Stanford Achievement Test (Kelley, Madden, Gardener, and Rudman, 1966) and the Metropolitan Achievement Test (Durost, Bixler, Wrightstone, Prescott, and Balou, 1970) are being administered in many of the schools where the Language Arts course is being used. Again, however, these tests do not test the precise topics covered in the CAI course.

The decision was made to develop a set of tests for external evaluation of the Language Arts curriculum. It was beyond the scope of the project to develop a broadly applicable language test, although there is a need for such a test in schools for the deaf. Instead, it was decided to write a criterion test to measure only the objectives of the grammar course. The test items were modeled on the items in the Language Arts course. The test was written for paper and pencil administration so it could be given to students who had not taken any CAI.

A preliminary version, containing 78 questions, was developed in May, 1971. This version was divided into eight subtests that covered the following topics: directions, parts of speech, noun phrases and double verbs, determiners, singular and plural noun forms, pronouns, subjects and predicates, and adjective transforms.

The 1971-72 version of the test covered most of the topics taught in the first 200 lessons of the course. The test had 108 questions plus one or two sample questions for each subtest. The test was divided into 15 subtests as follows:

Subtest 1 - Directions
Subtest 2 - Identification of nouns and pronouns
Subtest 3 - Identification of adjectives and determiners
Subtest 4 - Identification of verbs (including double verbs)
Subtest 5 - Identification of noun phrases
Subtest 6 - Choose the correct determiner
Subtest 7 - Choose the correct noun

Subtest 8 - Choose the correct pronoun
Subtest 9 - Choose the correct verb (tense and number)
Subtest 10 - Write singular and plural nouns
Subtest 11 - Negative transforms
Subtest 12 - Adjective transforms
Subtest 13 - Possessive noun phrases
Subtest 14 - Inflections of "to be"
Subtest 15 - Contractions

The 1971-72 version was administered to approximately 500 students in participating schools in the fall of 1971. The administration included the 76 hearing fifth-graders and 47 of the 204 hearing impaired students who were receiving math strands CAI but not the grammar curriculum. Responses on the test were stored on computer disk file as correct, incorrect or no response along with the student's name, IMSSS student number, IMSSS class number, sex, birthdate, date of test administration and number of grammar lessons completed on the date of testing. The test was given to as many of these same students as possible in May, 1972.

The goals of the course with lessons and subtests cross-referenced are listed in Appendix C.

1971-72 Formative Evaluation of the Language Arts Curriculum

The 1971-72 evaluation of the Language Arts curriculum for the deaf was intended to be exploratory and formative rather than summative. The emphasis of the assessment was on how well the curriculum meets its objectives rather than on how appropriate these objectives are to broader school goals. The 1971-72 assessment was intended to be as thorough as possible in meeting its aims.

Curriculum lessons. Difficulty levels for the lessons were studied as simple proportion correct in each lesson. Two proportions were generated for each lesson: one for the first 7-9 exercises over all students and one for all exercises over just those students who were not branched out after the first 7-9 exercises. A matrix of correlations for lesson i with lesson j ($i \leq j$) and a matrix of their associated standard errors of estimate was obtained in two ways: first, by using all students who completed the first 7-9 exercises in both lesson i and lesson j and, second, by using all students who completed all exercises in both lesson i and lesson j. A linear model was the only model used in considering the pair-wise relationships among the lessons, and there was no evidence to reject the model. The internal consistency of the lessons was estimated by the following form of the Kuder Richardson formula 20 suggested by Walker and Lev (1953):

$$KR = \frac{m}{m-1}\left(1 - \frac{\Sigma(Np_i)(Nq_i)}{N(N-1)s_x^2}\right)$$

where m is the number of items in the lesson,

N is the number of students who have completed all items in the lesson,

p_i is the proportion of students who answered the ith item correctly,

$q_i = (1-p_i)$ = proportion of students who answered the ith item incorrectly,

s_x^2 is variance of the lesson scores of the N students if each score is number of items answered correctly by the individual.

In this calculation we assume the matrix of inter-item correlations has a rank of one and that all the intercorrelations are equal.

Curriculum items. Item difficulty was examined as simple proportion correct on first responses to each item, however, all the items were classified according to curriculum objective represented and exercise task in accordance with each of the task categorization schemes so the effect of the curriculum objectives represented or the exercise task on the difficulty of the item could be estimated by comparing across categories and by using stepwise multivariate linear regression. Matrices of item point biserials and standard errors of estimate were generated for each lesson.

Subtests. Difficulty levels for the subtests were studied as simple proportion correct in each subtest. Matrices of correlations and standard errors of estimate were generated to determine the inter-relationships among the subtests. Only a linear model was considered as a basis for the inter-relationships, and there was no evidence to reject the linear model used. The internal consistency of the subtests was estimated by the Kuder Richardson formula 20 given above.

Subtests and lessons. It is important to determine the relationship between subtests and the curriculum lessons. In pre-testing, the subtests that reflect given objectives of the Language Arts curriculum should predict performance in lessons reflecting the same objectives. In post-testing, proficiency with respect to given objectives should be reflected both in the lessons and in the subtests. The assumed model of relationship between subtests and lessons was a linear model. Matrices of correlations and standard errors of estimate were generated for pre-test subtests and lessons and for post-test subtests and lessons. Lesson scores used in generating these matrices were obtained in two ways: first, only the initial 7-9 exercises in the lessons were used and all students who completed these exercises were included, second, all exercises in the lessons were used but only those students who completed all exercises in a given lesson and did not branch ahead after the initial 7-9 exercises were included.

Standard subtests. A linear model was again examined as a basis for relationships between curriculum lessons or the IMSSS Language Arts subtests and reading and language arts subtests from standard tests such as the Stanford Achievement Test (SAT). SAT scores were available for about 300 of the Language Arts students. Also, the test of English as a Foreign Language (TOEFL) was administered to about 25 pre-linguistically deaf high school students. The TOEFL is of particular interest as a measure of English usage by students whose "native language" is American Sign Language.

A linear model was examined as a basis for the relationship between IMSSS subtests or curriculum lessons and standard subtests. The curriculum lesson scores were obtained in the usual way, i.e., one set for all students who completed the initial 7-9 exercises in each lesson and a second set for all students who completed all exercises in each lesson. Matrices of correlations and standard errors of estimates were obtained.

Student characteristics. The following measures were obtained from about 300 CAI Language Arts curriculum students in the California School for the Deaf - Berkeley, the Oklahoma School for the Deaf - Sulphur, and the Texas School for the Deaf - Austin:

(1) chronological age,

(2) hearing loss in better ear,

(3) age of hearing loss,

(4) number of years in a residential school for the hearing impaired,

(5) sex,

(6) number of CAI Language Arts lessons completed,

(7) pre-test score,

(8) standard test scores.

These measures were entered as independent variables into multivariate stepwise regressions that take lesson score, post-test score, post-test subtest score, number correct among all items covering a given curriculum objective, and number correct under all items covering a given exercise task category, respectively, as the dependent variable. The intent of this analysis was to determine the relative importance of the student characteristics measured in accounting for variance in these variables.

Assessment of the IMSSS Language Arts test. The Language Arts test was studied as a test in itself. Reliability as internal consistency and precision was estimated by the Kuder Richardson formula 20 mentioned above. Predictive validity of the test was estimated by the relationship of the pre-test subtests to lesson performance. Some estimates of concurrent validity were obtained from the comparison of IMSSS subtests with standard subtests. Content validity was estimated by comparing the curriculum

objectives covered by the test with the full list of curriculum objectives. The curriculum objectives not covered by the 1972 test are listed in Appendix D.

Two forms of the IMSSS test were created in 1971-72. Two complete sets of items were obtained by writing for each item on the original test a second parallel item. The resulting pairs of items were then assigned at random to two forms of the test labeled Form A and Form B.

These forms were examined to see if they were parallel. According to Lord and Novick (1968) two distinct measurements X_{ga} and X_{ha} are parallel if for every subject, a, in the population, $\pi_{ga} = \pi_{ha}$ and $\sigma(E_{ga}) = \sigma(E_{ha})$, where π indicates measurements with the same true scores but possibly different error variances. More intuitively, two measurements are parallel if their expectations are equivalent and their observed score variances are equal. The degree to which the two forms are parallel was estimated by selecting eighty students at random from among the entire population taking the Language Arts curriculum and administering both Form A and Form B to all the students selected. Half of the students were selected at random and received Form A first; the remaining half of the students received Form B first.

Experimental Treatments

At the beginning of the 1971-72 school year the Language Arts curriculum students were assigned independently and at random to groups within each of three experiments.

Experiment I is comprised of two treatment groups. One group receives programmed correction messages that are tailored for specific, anticipated wrong answers. About half of the exercises in the curriculum include one or more of these programmed correction messages. Members of the second group in Experiment I do not receive these messages; they are told only that a given answer is "WRONG." In accordance with their Experiment II treatment group, both Experiment I groups receive the correct answer after the wrong answer response is given.

Experiment II is comprised of two treatment groups. One group is allowed three trials per exercise, the second group is allowed only one trial per exercise. The members of the first Experiment II group receive either a programmed correction message or the word "WRONG," depending on their Experiment I treatment group, after the first and second trial on an exercise. They are not given the correct answer explicitly until the third trial unless the correct answer is part of a programmed correction message. The correct answer is rarely included in these correction messages.

Experiment III again is comprised of two treatment groups. In one group, members are given an opportunity to type the correct answer after

it is explicitly given following a wrong answer. In the second group, the correct answer is given explicitly, but students are not requested to type the correct answer after it is given.

There are two groups under each of the three experiments yielding eight possible treatments under the experiments for any random student. The analyses of curriculum lessons and items, test subtests and items, subtest and lesson relationships, IMSSS curriculum and test relationships to standard tests, and student characteristics will be done separately for each of these eight treatment groups. Treatment groups will be collapsed and analyses for the groups will be combined when there is no demonstratable difference between them. Analyses for the hearing impaired math strands students and the hearing Language Arts students will also be kept separate yielding ten separate sets of analyses in all.

Interaction of CAI with Classroom Instruction

In March 1972, questionnaires surveying use of Language Arts materials were mailed to 72 schools for the deaf and hard of hearing. Information concerning both commercial and non-commercial materials was requested. Instances in which the scope of the questionnaire appeared too limiting are being followed-up by personal interviews.

There are three purposes of this survey. First, achievement differences between classes of students that cannot be accounted for by the CAI intervention may be explained by the approach being used in the classroom. Further, the CAI sessions may supplement some classroom treatments better than others. The survey is intended as a basis upon which these questions can be investigated in 1972-73. Second, the survey should indicate ways in which the Language Arts curriculum can be better coordinated with the activities of the classroom teacher. Specific aspects of the curriculum may be usefully related to specific materials. Third, the survey should provide a check of the content validity of the curriculum. In selecting the objectives and writing the lessons for the curriculum, priorities for presenting aspects of Language Arts curriculum were made operational. How valid and realistic these priorities are will be indicated by the survey.

Study of Economics and Technology of the Network

Introduction

The primary effort under this contract has been, and will continue to be, the development and evaluation of computer-based curriculums that improve the quality of education for deaf children. However, development and evaluation are insufficient in themselves to have a practical payoff for substantial numbers of deaf children. For this reason, we have investigated the operational implementation of our CAI development efforts. A central aspect of this implementation is basic economics of CAI--its cost, performance, and degree of substitutability for other

inputs into education of the deaf. We discuss these economic questions briefly below and describe a number of specific implementation alternatives. These alternatives are suggestive rather than exhaustive, and will be elaborated in the coming months.

Basic Economics of Providing CAI

The cost per operational CAI terminal in a school for the deaf depends on many factors related to the basic organization of the system that provides the service. In the next section, we discuss a number of alternatives and reference more detailed cost estimates for them. In this section, analyses of basic economic trade-offs will simply take conservative cost values based on estimates for the immediate future; we emphasize, however, that many components of these costs are declining.

Our basic cost assumption is that for $300 per month a teletype terminal can be maintained in a typical school. This cost includes amortization of capital costs, use of the central computer system, communications, proctoring, and supplies. It does not include any expenditures associated with making classroom space available. We also assume that for 20 days per month an average of 25 student sessions per day are given at each teletype. Thus, we assume 500 sessions per terminal per month at a cost of $300, or $.60 per session. We have observed high variance in the number of sessions per terminal per day obtained by different schools, and with effective scheduling it is feasible to obtain many more sessions per terminal per day than the 25 we assume. Many schools for the deaf are obtaining utilization rates in the range of 35-40 sessions per terminal per day, suggesting the possibility of substantially lower costs per session than the $.60 that we use. Also, we have assumed a 6-hour school day, the residential schools for the deaf are using their terminals 8-10 hours per day, further increasing the number of sessions per terminal per day and further decreasing the cost per session.

The decision of whether to provide CAI and how much CAI to provide depends not only on cost per session but on two other critical factors. First, of course, is the performance of CAI in raising student achievement, and this aspect is discussed elsewhere in the proposal. Second is the issue of what must be given up in order to have CAI. Given that budgets are inevitably constrained, the more CAI an administrator provides his students, the less he can provide of something else. A requirement of good administration is to make these trade-offs explicitly, both in terms of their cost and of their performance. Due to the low student-to-staff ratios, a larger fraction of resources goes into staff in schools for the deaf than in other schools, and the most feasible way of financing CAI is, therefore, through slight increases in the student-to-staff ratio. This method is the most feasible even if new resources for acquiring CAI come from outside the school; the new funds could have been allocated to lowering the ratio of students to staff rather than to providing CAI.

The trade-offs are summarized in the following equation adapted from Jamison (1971).

$$S^* = S + \left[\frac{(S*W*(1 - R)) + (C(N)*S^2*R)}{W - (C(N)*S*R)} \right] \qquad (1)$$

where S^* is student-to-staff ratio after introduction of CAI,

S is student-to-staff ratio before introduction of CAI,

W is average annual salary of the instructional staff,

R is ratio of the post-CAI instructional cost per student to the pre-CAI cost, and

$C(N)$ is the cost of providing a student N sessions of CAI per year.

To estimate the "opportunity" cost of CAI, we solve equation (1) for S^* as a function of N (the number of CAI sessions per student per year) under the assumption that $R = 1$; i.e., we assume that CAI is introduced into schools for the deaf with no net increase or decrease in per-student instructional costs. To complete the calculation we need to know staff salaries and staff-to-student ratios, and Table 13 displays this information for a number of different types of schools for the deaf. For the present illustration, we consider public day schools where the instructional staff salaries averaged \$8760 per year and the student-to-instructional-staff ratio was 4.5. We have, then, $S = 4.5$, $W = 8760$, $R = 1$, and, using the previous assumptions about costs, $C(N) = \$.60N$. Equation (1) becomes:

$$S^* = 4.5 + 12.15N/(8760 - 2.7N) . \qquad (2)$$

Table 14 shows the student-to-staff ratio calculated from equation (2) required to leave per-student instructional costs unaltered if each student has N CAI sessions per year for six values of N.

It is evident from Table 14 that substantial amounts of CAI are feasible with only minor increases in student-to-staff ratios. For example, increasing the student-to-staff ratio by 10 percent, from 4.5 to 4.95, would allow each child to have almost two CAI sessions daily (300 per year). The question facing the school administrator is whether the achievement gains resulting from this much CAI would counterbalance the achievement losses (if any) resulting from the slightly lower staff-to-student ratio.

Implementation Alternatives

In the preceding section we outlined the basic economic considerations that would lie behind an administrative decision to utilize CAI in schools for the deaf. There remains the question of exactly how to implement the results of the development efforts supported by the Bureau of Education for the Handicapped at Stanford. We are analyzing four

TABLE 13

Salaries and Student-to-Staff Ratios in Schools for the Deaf

for the 1968-69 School Year

Type of school	Average annual salary of instructional staff	Ratio of students to instructional staff
Public Res. Schools	$7564	5.6
Private Res. Schools	6251	4.9
Public Day Schools	8760	4.5
Private Day Schools	6009	4.5
Public Day Classes	7721	3.9
Private Day Classes	7740	4.4

Source: "Tabular Statement of American Schools and Classes for the Deaf, October 31, 1968," pp. 622-623 of the Directory of Services for the Deaf in the United States--American Annals of the Deaf, May, 1969.

TABLE 14

Student-to-Staff Ratio Required to Leave Per-Student Instructional Costs Constant with Implementation of CAI[a]

Number of CAI sessions per year	Student-to-instructional-staff ratio
0	4.50
100	4.64
200	4.79
300	4.95
500	5.30
1000	6.50

[a]The figures in this table assume a pre-CAI student-to-instructional-staff ratio of 4.5 and an average annual salary for the instructional staff of $8760. CAI is assumed to cost $.60 per 6 to 10 minute session.

possibilities for the 1973-74 school year and after, when the present phase of our development efforts will be concluded.

The first implementation alternative would consist of operational utilization of the IMSSS facility at Stanford, with the Stanford staff continuing in their liaison, maintenance, and administrative roles. By the beginning of the 1973-74 school year, up to 300 terminals at various locations around the country could be made available enabling 5,000 to 10,000 deaf students to receive CAI as a standard part of their curriculum. The total cost per terminal per month would be between $250 and $400. This approach would have the advantage of being a direct extension of the services currently provided by Stanford and implementation problems would be minimized. Furthermore, as curriculum development for the deaf continues at Stanford, new and revised curriculum materials would be immediately available to all students in the network.

The second implementation alternative is identical to the first except that major administrative and operational responsibilities would be transferred to a school serving the deaf community, for example, Kendall Demonstration Elementary School. That school would be responsible for liaison with other schools, communications, teletype maintenance, and administration of everything except the central computation facility at Stanford. The major attraction of this approach lies in the gradual but explicit transfer of technological expertise and control from the developers of the CAI system to the users.

A third alternative would be to implement the curriculums developed at Stanford with stand-alone mini-computer systems. The central processor on such systems requires no operator, and it is capable of serving 8 to 16 student terminals with relatively simple curriculum materials. Jamison, Suppes, and Butler (1970) provide a more detailed description and cost analysis for systems of this sort. Communication and multiplexing costs would be minimized by the small geographical dispersion of users. Per-terminal costs using this approach would be approximately two-thirds to three-fourths the costs involved in the first and second alternatives. However, the range of curriculums offered on mini-systems is more limited than in the first and second alternatives, and curriculum revision is far more difficult.

A fourth alternative, diametrically opposite to the third, would be to establish a large CAI center for the deaf that would be capable of simultaneously running 500 to 1,500 terminals. Such a center would require nationwide communications. It could take full advantage of new and revised curriculums as they become available, and it could provide a wider range of curriculums than could a mini-system. Ball and Jamison (1972) provide a detailed description and cost analysis for a system capable of widely distributing the curriculums now being developed for the deaf. Ball and Jamison conclude that use of communication satellites appears to be an economically attractive way of distributing CAI to a population as dispersed as that of deaf students. Per-terminal costs

for a large-scale system such as this would probably fall between those of a mini-system and those of an expanded Stanford-based system. The difficulty with proceeding directly to this option is the substantial time lag between decision and implementation and the administrative difficulties inherent in expanding a small scale of operations to a very large one.

Grammatical and Semantic Analysis of Deaf Students' Talk on Teletypes

The SAMPLE Corpus

An important first step in examining the language of hearing-impaired students is the collection and analysis of a corpus of writing samples. We have begun an intensive analysis of a small sample of the written language of deaf students obtained from Kendall School for the Deaf in Washington, D.C. and the California School for the Deaf in Berkeley, California. This corpus, which we call SAMPLE, has been edited and divided into 1311 sentences. An informal way to describe these sentences is to say that they are analogous to the "complete thoughts" of classical grammar. Nearly all of the "complete thoughts" in the writing samples were terminated by conventional punctuation so the original corpus was modified very little in selecting the sentences.

Sentence length analysis. To analyze the length of a sentence, we let a word be defined as an unbroken string of the following characters:

$$a,b,c,\ldots,z,0,1,2,\ldots,9,-\ .$$

The dash (-) is used to indicate several words that should be thought of as single semantic units, such as

junior-high,
bay-bridge,
jr-league,
aunt-geraldine,
mr-ben-provance.

We ignored the distinction between capital and small letters because it is doubtful that the upper-lower-case distinction carries much semantic import. The length of a sentence was defined as the number of words it contains. This definition does not correspond to many standard definitions of morphology. However, it is appropriate for semantic analysis.

In written English the characters of punctuation often indicate the phrasing of sentences. We have not considered this as a part of the description of the SAMPLE corpus. Punctuation characters are ignored in the analysis.

The mean length of sentences in the SAMPLE corpus is 8.92, with a mode of 6. The variance is 25.76, giving a standard deviation of 5.08.

TABLE 15

Length Distribution of Sentences in SAMPLE

Prediction of Distribution Using Negative-binomial Distribution[a]

Length X	Freq. X	Theor. freq. X	Theor. prob.	Chi square
1	10	20.70	.02	5.53
2	15	50.42	.04	24.88
3	65	78.87	.06	2.44
4	124	100.46	.08	5.51
5	134	113.36	.09	3.76
6	147	118.04	.09	7.11
7	129	116.04	.09	1.45
8	116	109.27	.08	.42
9	102	99.48	.08	.06
10	80	88.16	.07	.76
11	78	76.42	.06	.03
12	61	65.04	.05	.25
13	58	54.49	.04	.23
14	29	45.04	.03	5.71
15	33	36.80	.03	.39
16	20	29.76	.02	3.20
17	28	23.85	.02	.72
18	17	18.96	.01	.20
19	15	14.97	.01	.00
20	8	11.74	.01	1.19
21	7	9.15	.01	.51
22	5	7.10	.01	.62
23	7	5.48	.00	.42
24	4	4.21	.00	
25	5	3.22	.00	.33
26	3	2.45	.00	
27	0	1.86	.00	
28	1	1.41	.00	.52
29	3	1.07	.00	
30	1	.80	.00	
31	1	.60	.00	
32	1	.45	.00	
33	1	.34	.00	
34	0	.25	.00	
35	1	.19	.00	

(continued)

Table 15, continued

Length X	Freq. X	Theor. freq. X	Theor. prob.	Chi square
36	0	.14	.00	
37	0	.10	.00	
38	1	.08	.00	
39	0	.06	.00	
40	0	.04	.00	
41	0	.03	.00	
42	1	.02	.00	8.19

Residual Expected Frequency = .06
Sum of Theoretical Probabilities (Before Residual) = 1.00
Chi Square Sum = 74.50
Degrees of Freedom = 23

[a]Parameters are P = .31 and R = 3.52. Distribution is started at X = 1, and values are shifted.

The distribution has a skew of .58, measured by Pearson's skew statistic. The longest sentence length was 42. Table 15 gives the distribution of the sentence lengths in SAMPLE.

There is an interesting theoretical problem connected with the length of the sentences in a corpus, and that is to account for the distribution of lengths with a formal model of utterance generation. A classical approach to the problem of finding underlying models is to look for functions that "fit" the empirical distribution, and then ask what behavioral models the functions suggest. Three plausible functions are the geometric, the poisson, and the negative binomial. Using the maximum likelihood method to estimate the parameters associated with these distributions, and then computing the chi-squares as measures of the goodness of fit, we have listed the results in Table 16.

TABLE 16

Prediction of Sentence Length in SAMPLE

Results of Several Models

Model	Sum of theoretical probabilities	Chi square sum	Residual	Degrees of freedom
Geometric distribution	.99	586.52	8.90	32
Poisson distribution	1.00	2093.80	0.00	14
Negative binomial distribution	1.00	74.50	0.06	23

Table 16 shows that of the three theoretical distributions the negative binomial provides the best fit of the empirical data. Interestingly, this result corroborates analyses we have completed on other corpora, including the speech of hearing children (ages 20-36 months) and hearing adults. Table 15 gives more detailed information on the negative binomial fit to the distribution of sentence lengths.

Vocabulary and dictionary construction. There are 11,697 words in SAMPLE, but only 1598 different words are used, i.e., 11,697 tokens and 1,898 types. This tally indicates a fairly small functional vocabulary for deaf students. Many of the words in SAMPLE occur out of proportion

to their occurrences in English, and we plan to compare word frequencies observed in SAMPLE and other corpora obtained from hearing-impaired students with Kucera and Francis' Computational Analysis of Present-Day American English (1967). Appendix E lists the 100 most frequently occuring words in SAMPLE in the order of their frequency of occurrence.

In order to automate the analysis of natural language so that sufficiently large corpora can be used, it is necessary to represent in the computer the syntactic and semantic properties of the vocabulary. In part, this is a programming problem that involves technical matters such as the representation, recall, and updating of information in a large data structure. It is also a theoretical problem requiring an examination of the language of the deaf student to determine what kinds of syntactic and semantic categories to create in the data structure.

We have classified the 1893 different words in SAMPLE into lexical categories indicating how these words were used by the deaf students in sentences. Since some words can be used in different ways in different sentences it is necessary to give multiple classifications to many words. Table 17 lists the categories used in this dictionary, documenting how many words are in each category, and giving the intuitive meaning of each. The syntactic categories are selected to correspond to the semantic objects represented in the data base. Multiple categories for words that can function in several ways are indicated by commas in the categories. Contractions are indicated by the symbol '#', which indicates that a single word combines two semantic roles. Such a word as "you're" is categorized as a personal pronoun followed by a linking or auxiliary verb. This is in keeping with the traditional view of contractions.

The grammar of noun-phrases in SAMPLE. It is our experience that noun-phrases dominate much natural language, and this is true of SAMPLE. By editing the text and selecting the parts of sentences that seem to be noun-phrases, we find that there are 2366 noun-phrases in SAMPLE.

A methodological assumption that we have found useful in linguistics research is that it is important to construct a theory that accounts for the main features of language and indicates what are the remaining problems. The construction of a grammar for noun-phrases is an example of this assumption. We look first at the noun-phrases because they are the predominant feature of SAMPLE. Moreover, the addition of the concept of a probabilistic grammar is also a useful part of this approach since it gives a sense of the relative importance that various structures have in the corpus.

In Appendix F, we review some formal notions, such as context-free grammar and probabilistic grammar, and apply these ideas to the noun-phrase fragment of SAMPLE. By constructing probabilistic grammars for the noun-phrase fragment of SAMPLE we are attempting to test some hypotheses about the kinds of structures present. We are assuming that we already know something about the kinds of structure we will find in noun-phrases. For example, we expect to see some adjective phrases,

TABLE 17

Grammatical Categories Used for the Dictionary for SAMPLE

Frequency	Grammatical category	Explanation (examples)
847	n	common nouns - (car, cow)
385	v	common verbs - (drew, talk, watch)
208	adj	common adjectives - (delicious, wet)
160	pn	proper nouns - (albany-hs, desi-arnaz)
55	adv	adverbs - (afterwards, later)
25	padj,n#aux,n#link	words that can be either a possessive adjective, or a noun followed by an auxiliary verb, or a noun followed by a linking verb - (children's, (parent's)
23	prep	prepositions - (about, of)
15	n,v	noun or verb - (answer, cost)
15	pron	pronoun (other than personal) - (anyone, something)
14	persp	personal pronouns - (i, they)
13	padj,pn#aux,pn#link	words that can be either a possessive adjective, or a proper noun followed by an auxiliary verb, or a proper noun followed by a linking verb - (jack's, jill's)
12	qu,pron	either a quantifying word or a pronoun - (all, that)
12	int	interjections - (good-by, please)
11	conj	conjunctions - (and, but)
9	prep,adv	either a preposition or an adverb - (around, outside)
9	mod	modal verbs - (can, must)
9	padj	possessive form of a noun - (doctor's, parents')
8	misc	words defying classification - (accbiet)
7	link,aux	linking or auxiliary verb - (am, were)

(continued)

Table 17, continued

Frequency	Grammatical category	Explanation (examples)
7	n,adj	noun or adjective - (gold, south)
7	pronadj	possessive form of personal pronouns - (his, mine)
6	v,mod	common or modal verb - (go, wants)
4	v,aux	common or auxiliary verb - (do, have)
4	intadv	interrogative adverb - (how, where)
3	art	articles - (a, an, the)
3	mod#neg	modal verb followed by a negating particle - (can't, couldn't)
3	qu	quantifying word - (every, only)
2	aux#neg,link#neg	auxiliary verb followed by negating word, or a linking verb followed by a negating particle - (aren't, wasn't)
2	link	linking verb - (became, become)
2	v#neg,mod#neg	common verb followed by a negating word, or a modal verb followed by a negating word - (didn't, don't)
2	persp#aux,persp#link	personal pronoun followed by an auxiliary or linking verb - (he's, we're)
2	pron#aux,pron#link	pronoun followed by an auxiliary or linking verb - (i'm, that's)
2	neg	negating word - (no, not)
2	aff	affirmative word - (ok, yes)
2	inter	interrogative pronoun - (what, who)
1	n,adv	noun or adverb - (back)
1	v,adj	live
1	v#neg,aux#neg	hadn't
1	persp,pronadj	her
1	pron#mod,pron#aux	i'll
1	pron#aux	i've
1	prep,conj	then
1	persp#mod	we'll

some prepositional phrases, and so on. The grammar is written with this in mind. What we do not know is the tendency to use, say, several adjectives, or the tendency to use prepositional phrases.

The grammar GS1 for the noun-phrase fragment of SAMPLE is designed to make some simple tests. The main structure that we have assumed for the noun-phrases is: an (optional) adjective phrase, followed by a noun or noun-substitute, followed by an (optional) prepositional phrase. The optional prepositional phrase then contains something like a noun-phrase as the object of a preposition. GS1 is designed to test the differences between the noun-phrase that is the object of the preposition, and the more general noun-phrase.

Table 18 gives the rules of the grammar GS1 together with the parameters estimated from the noun-phrase fragment of SAMPLE.

The rules are labeled with ordered pairs of numbers, for easy reference. The 2-rules, the rules that have a '2' as the first number of the label, generate the general noun-phrases, since 'np' is the start symbol of GS1. The 5-rules generate the noun-phrases that are objects of the prepositions. Notice that rule (2,1) has an associated probability of .63, while similar rule (5,1) has a probability of .82. This indicates that there is a greater tendency for a noun or pronoun to stand alone (without modifying adjectives) as the object of a preposition than in the main noun-phrase. Similarly, compare the 3-rules with the 7-rules. The 3-rules generate adjective phrases for use with the main noun (or pronoun) of the noun-phrase, while the 7-rules generate adjective-phrases for use in modifying the noun (or pronoun) that occurs as an object of the prepositional phrase. The probabilities indicate: given that we are using an adjective phrase, the tendency to use a pronominal adjective is about the same (.05 in each case); however, the tendency to use more than one adjective is .05 for rule (3,2) but .00 for the corresponding rule (7,2).

There is no one grammar for the noun-phrase fragment of SAMPLE. We have given here a grammar that accounts for most of the noun-phrases. For example, there were 330 noun-phrase types, representing 2366 tokens. Out of these, 182 types were recognized by GS1, representing 2150 tokens. This means that 91 percent of the noun-phrases were recognized by the grammar GS1. Moreover, the grammar indicates some statistical differences in certain kinds of structures present in the noun-phrases.

From the view of the goodness of fit, the grammar is not very acceptable. The chi-square sum is 2502, with 11 degrees of freedom, and this is not a good fit, especially for a noun-phrase grammar. Table 19 lists all the noun-phrases, together with the observed and expected frequencies, and the chi-square contributions.

Semantics of the context-free grammar. The importance of the context-free grammar is that the semantics can be a natural extension of the syntax. Each rule of the grammar is assigned a semantic function corresponding to

TABLE 18

Grammar GS1 for Noun-phrases from SAMPLE

Start Symbol Is NP

Label	Probability	Rewrite rule
(1,1)	.1752	npl → adp nl
(1,2)	.8248	npl → nl
(2,1)	.6344	np → npl
(2,2)	.1755	np → quart npl
(2,3)	.0277	np → np prepp
(2,4)	.1149	np → np npl
(2,5)	.0475	np → np conj np
(3,1)	.2484	adp → adj
(3,2)	.0459	adp → adp adj
(3,3)	.6472	adp → pronadj
(3,4)	.0585	adp → padj
(4,1)	.1212	quart → qu
(4,2)	.8788	quart → art
(5,1)	.8205	pnp → pnpl
(5,2)	.1795	pnp → pquart pnpl
(6,1)	.2179	pnpl → padp nl
(6,2)	.7821	pnpl → nl
(7,1)	.3529	padp → adj
(7,2)	.0000	padp → padp adj
(7,3)	.6471	padp → pronadj
(8,1)	.2143	pquart → qu
(8,2)	.7857	pquart → art
(9,1)	1.0000	prepp → prep pnp
(10,1)	.6042	nl → n
(10,2)	.0182	nl → pron
(10,3)	.3165	nl → persp
(10,4)	.0007	nl → inter
(10,5)	.0603	nl → pn

TABLE 19

Some High-frequency Noun-phrase Types in Relation to Grammar GS1

Chi Square Contributions

Observed frequency	Expected frequency	Chi square contribution	Noun-phrase type
794	355.996	537.673	persp
294	165.281	99.467	art n
221	93.465	172.664	pronadj n
213	679.743	319.801	n
92	67.849	8.245	pn
52	38.921	4.065	n n
39	35.878	.192	adj n
34	8.724	70.365	art adj n
31	9.464	46.759	art n n
29	22.797	1.426	qu n
17	20.522	.445	pron
17	5.352	23.224	pronadj n n
16	8.442	5.901	padj n
2150.000	2150.0000	2502.1335	TOTALS (including some types not displayed)

Degrees of Freedom = 11

Chi Square/Degrees of Freedom = 227.4667

the way the rule introduces new concepts into the meaning of the sentence. For example, the first rule of our grammar for the noun-phrase fragment of SAMPLE allows an adjective phrase to modify a noun-phrase, as in these examples from SAMPLE:

big boy
my black hat

A standard function that we have found to be very successful with adjective phrases is that of intersection. Thus, the meaning of the phrase 'big boy' is the intersection of the set of big things with the intersection of the set of boys. We may symbolize this by

$$[\text{big}] \cap [\text{boy}]$$

using standard set notation, plus the brackets to indicate the denotations of the words themselves. The meaning of 'my black hat' is then given by

$$[\text{my}] \cap [\text{black}] \cap [\text{hat}] .$$

More complex functions are needed for articles, quantifiers, verbs, and adverbs.

It should be emphasized that we are not in a position to understand all constructions that the deaf student uses. We need, as a beginning, to obtain a few of the major constructions. This is the purpose of collecting a corpus of deaf writing for further research.

The TALK Program

The data collected in SAMPLE is inadequate for the following reasons.

1) SAMPLE consists of teacher selections of students' writing. Most of the samples are classroom exercises rather than spontaneous expressions.

2) The total size of 1311 sentences is too small for serious linguistic analysis. The corpora of hearing children that we have analyzed have included as many as 10,000 sentences, and some future corpora will contain more than 40,000 sentences.

3) Relevant data in greater quantity can be collected by obtaining sentences typed at CAI terminals by students.

Therefore, we are collecting and propose to analyze a corpus of deaf written language using the TALK program currently in operation on our system.

Using this program we can obtain a sufficiently large corpus of the spontaneous writing of deaf students. The TALK program is designed to let two or more students type messages to each other on teletypes. The messages are spontaneous, and the program records these messages (anonymously) for our use in linguistics research. Since November of 1971 we

have collected about 3000 sentences written by deaf students using the TALK program.

With the additional samples obtained from the continuing use of TALK by deaf students, the program will provide us with the most extensive corpus of the spontaneous writing of the deaf that has, to our knowledge, been collected. It will form the basis of research directed toward the construction of a computer interaction system.

An Interactive System for Elementary Mathematics

The syntactic-semantic structures contained in common textbooks of elementary mathematics have been carefully examined as part of the Institute's work. The following is a sample of sentences from Sets and Numbers (Suppes, 1969).

A set is a collection of things.
We may use pictures and braces to show sets.
Pair the sets!
Sets are equal when they have the same things in them.
Which are equal sets?
Sets are unequal when they do not have the same things in them.
We call $\neq$ the not-equal sign.
Choose = or $\neq$!
A set may have more than one tning in it.
A set may have only one thing in it.
The set with no things in it is the empty set.
Which sets have more than one thing in them?

The variety of syntactic forms present in Sets and Numbers is limited and regular. Given both the simplicity of the syntactic forms used in Sets and Numbers and our analysis of the written language of hearing-impaired students, it will be possible to construct an interactive CAI system for deaf students using elementary mathematics as the subject matter.

The first examples of having an interactive system for elementary mathematics would be aimed at augmenting the strands mathematics program, especially the problem-solving strand, now currently being used by a large number of the deaf students currently registered in our CAI system. In the first stage we would introduce meaningful, simple tutorial instruction, without stereotype, by careful attention to the grammar and semantics of elementary mathematical statements. We believe that this can be done in an effective way. At the second stage we would plan to accept simple questions from the students about elementary mathematical concepts. We expect to make much progress on this second stage during the coming year.

References

Ammons, R. B., and Ammons, H. S. Full-range picture vocabulary test. Missoula, Montana: Psychological Test Specialists, 1948.

Ball, J., and Jamison, D. Communication economics of interactive instruction for dispersed populations. Technical Report No. 190, Institute for Mathematical Studies in the Social Sciences, Stanford University, September 15, 1972.

Boatner, M. T., and Gates, J. E. A dictionary of idioms for the deaf. West Hartford, Conn.: American School for the Deaf, 1966.

Bradley, J. V. Distribution-free statistical tests. Englewood Cliffs, N. J.: Prentice-Hall, 1968.

Cooper, R. Unpublished paper and pencil test on morphological rules. Lexington School for the Deaf, Jackson Heights, New York, 1965.

Daily, J. T. Language facility test. Alexandria, Va.: Allington Corporation, 1968.

Diagnostic reading test. Newstime. Columbus, Ohio: American Education Publications, 1963.

Doctor, Powrie Vaux (Ed.), Directory of services for the deaf in the United States - American Annals of the Deaf. Washington: Gallaudet College, 1969.

Draper, N. R., and Smith, H. Applied regression analysis. New York: John Wiley, 1966.

Dunn, L. M. Peabody picture vocabulary test. Minneapolis, Minn.: American Guidance Service, 1959.

Durost, W. N., Bixler, H. H., Wrightstone, J. W., Prescott, G. S., and Balou, I. H. Metropolitan achievement test. New York: Harcourt, Brace, Jovanovich, 1970.

Fitzgerald, E. Straight language for the deaf. Washington: The Volta Bureau, 1949.

Gates, A. I., and MacGintie. Gates-MacGintie reading tests. New York: Teachers College Press, Columbia University, 1965.

Gates, A. I., Huber, M. B., and Salisbury, F. S. Macmillan readers. New York: Macmillan, 1966.

Gentile, A., and Di Francesca, S. Academic achievement test performance of hearing impaired students. Washington: Office of Demographic Studies, Series D, Number 1, September, 1969.

Hays, W. L. Statistics for psychologists. New York: Holt, Rinehart and Winston, 1963.

Jamison, D. Alternative strategies for elementary education in Indonesia: A cost-effectiveness analysis. Research Paper No. 46, Graduate School of Business, Stanford University, September, 1971.

Jamison, D., and Ball, J. Communication economics of computer-assisted instruction for rural areas: Satellite vs. commercial phone systems. Paper presented at the 22nd International Astronautical Congress of the International Astronautical Federation, Brussels, September, 1970.

Jamison, D., Fletcher, J. D., Suppes, P., and Atkinson, R. C. Cost and performance of computer-assisted instruction for education of disadvantaged children. In J. Froomkin and R. Radner (Eds.), Education as an Industry, National Bureau of Economic Research, Columbia University Press, 1972, in press.

Jamison, D., Suppes, P., and Butler, C. Estimated costs of computer-assisted instruction for compensatory education in urban areas. Educational Technology, 1970, 10, 49-57.

Kelley, T. L., Madden, R., Gardener, E. F., and Rudman, H. C. Stanford achievement test. New York: Harcourt, Brace, Jovanovich, 1966.

Kucera, H., and Francis, W. N. Computational analysis of present-day American English. Providence, Rhode Island: Brown University Press, 1967.

Language usage test. Unpublished test developed at the Clarke School for the Deaf, Northampton, Mass.

Lee, J. M., and Clarke, W. W. Lee-Clarke reading test. Los Angeles: California Test Bureau, 1958.

Lenneberg, E. H. Biological foundations of language. New York: John Wiley, 1967.

Lord, F. M. Some test theory for tailored testing. In W. H. Holtzman (Ed.), Computer assisted instruction, testing, and guidance. New York: Harper and Row, 1971. (a)

Lord, F. M. Robbins-Monro procedures for tailored testing. Journal of Educational and Psychological Measurement, 1971, Vol. 31, No. 1, 3-31. (b)

Lord, F. M., and Novick, M. R. Statistical theories of mental test scores. Reading, Mass.: Addison-Wesley, 1968.

Marshall, E. Unpublished paper and pencil test of expressive language for the deaf. California School for the Deaf, Berkeley, California, 1962.

McCarthy, J. J., and Kirk, S. A. Illinois test of psycholinguistic ability. Urbana, Illinois: University of Illinois Press, 1963.

McCracken, G., and Walcutt, C. C. Basic reading. Philadelphia, Pa.: J. B. Lippincott, 1964.

Moss, M. H. Tests of basic experiences. Monterey, California: California Test Bureau, 1970.

Myklebust, H. R. Picture story language test. In H. R. Myklebust, (Ed.), Development and disorders of written language, Vol. 1. New York: Grune and Stratton, 1965.

Rawlings, B. Summary of selected characteristics of hearing impaired students. Washington: Office of Demographic Studies, Series D, Number 5, June, 1971.

Roberts, P., Ross, C. S., and Boyd, J. The Roberts English series. New York: Harcourt, Brace, Jovanovich, 1970.

Robinson, H. M., Monroe, M., and Artley, A. S. The Scott Foresman basic readers. New York: Scott-Foresman, 1962.

Rush, M. L. The language of directions. Washington: Alexander Graham Bell Association for the Deaf, 1970.

Russell, D. H., and Ousley, O. The Ginn basic readers. Boston: Ginn, 1968.

Schrammel, A. H., Hoag, A., Humble, E., Robinson, B., and Wipf, A. Kansas primary reading test. Emporia, Kansas: Bureau of Educational Measurements, Kansas State Teachers College, 1935.

Stillwagon, N., and Leake, J. D. Language skills for Americans. Denver: Department of Instruction, Denver Public Schools, 1952.

Stokoe, W. C., Goldberg, J. P., Covington, V. C., LaRue, M. S., Wormeldorf, A., and Bornstein, H. Generating English sentences - tests. Washington: Gallaudet College Press, 1967.

Stroud, J. B., Hieronymus, A. N., and McKee, P. Primary reading profiles. Boston: Houghton Mifflin, 1957.

Suppes, P. Some theoretical models for mathematics learning. Journal of Research and Development in Education, 1967, 1, 5-22.

Suppes, P. Stimulus response of finite automata. Technical Report No. 133, Institute for Mathematical Studies in the Social Sciences, Stanford University, June 19, 1968.

Suppes, P. Sets and numbers. Books K-2, New York: L. W. Singer, 1968. Books 3-6, New York: L. W. Singer, 1969.

Suppes, P., and Morningstar, M. Computer-assisted instruction. Science, 1969, 166, 343-350.

Suppes, P., Fletcher, J. D., Zanotti, M., Lorton, P. V., and Searle, B. W. Evaluation of computer-assisted instruction in elementary mathematics for hearing-impaired students. Technical Report No. 194, Institute for Mathematical Studies in the Social Sciences, Stanford University, 1972.

Suppes, P., Fletcher, J. D., and Zanotti, M. Models of individual trajectories in computer-assisted instruction for deaf students. Technical Report No. 197, Institute for Mathematical Studies in the Social Sciences, Stanford University, 1972.

Withrow, F. B. Illinois communication scale. Jacksonville, Ill.: Illinois School for the Deaf, 1966.

APPENDIX A

Third Grade Vocabulary List for the Language Arts Course

able ADJ.
about ADV.
across PREP.
act V.
afraid ADJ.
after PREP.
afternoon N.
again ADV.
against PREP.
all DET.
almost ADV.
alone ADJ.
along PREP.
also ADV.
always ADV.
am V.
and CONJ.
angry ADJ.
another DET.
any DET.
apple N.
are V.
arm N.
around PREP.
asleep ADJ.
as ADV.
ate V.
at PREP.
aunt N.
away ADV.
a DET.

baby N.
back ADV.
bad ADJ.
bag N.
ball N.
bank N.
bang INT.
basket N.
bear N.
beautiful ADJ.
beat V.
because CONJ.
bed N.
before PREP.
began V.
behind PREP.
below PREP.
bell N.
best ADJ.
better ADJ.
between PREP.
be V.
bicycle N.
big ADJ.
bigger ADJ.
birthday N.
bite V.
bit V.
black ADJ.
blanket N.
blew V.
block N.
blue ADJ.
boat N.
both DET.
bottom N.
bought V.
box N.
boy N.
brave ADJ.
bread N.
break V.
breakfast N.
bring V.
bright ADJ.
brown ADJ.
brook N.
brother N.
broken V.
brought V.
built V.
busy ADJ.
business N.
but CONJ.
butter N.
by PREP.

cage N.
call V.
came V.
can V.
candy N.
cart N.
car N.
carry V.
care V.
castle N.
cat N.
catch V.
caught V.
cheese N.
children N.
chief N.
circus N.
city N.
clean ADJ.
clever ADJ.
climb V.
close V.
clop INT.
clock N.
clothes N.
cloud N.
cloth N.
coat N.
cold ADJ.
come V.
coming V.
cool ADJ.
corn N.
corner N.
course ID.
could V.
country N.
cow N.
cried V.
crowd N.
cry V.
cup N.
cut V.

danger N.
dark ADJ.
day N.
deer N.
deep ADJ.
did V.
different ADJ.
dig V.
dinner N.
does V.
dog N.
door N.
down ADV.
do V.
dress N.
drink V.
drive V.
dry ADJ.
duck N.

easy ADJ.
eat V.
edge N.
egg N.
eight DET.
either CONJ.
elephant N.
else ID.
empty ADJ.
end N.
engine N.
enough ADV.
ever ADV.
every DET.
even ADV.
evening N.

face N.
fall V.
family N.
farm N.
far ADV.
farmer N.
fast ADV.
faster ADV.
fat ADJ.
father N.
feather N.
feed V.
feet N.
feel V.
fell V.
felt V.
fence N.
few DET.
field N.
fill V.
fine ADJ.
find V.
finger N.
first ADJ.
fire N.
fish N.
five DET.
flag N.
flew V.
fly V.
foot N.
food N.
foolish ADJ.
for PREP.
forest N.
forth ID.
four DET.
found V.
free ADJ.
fresh ADJ.
friendly ADJ.
friend N.
from PREP.
front N.
fruit N.
full ADJ.
fun N.
funny ADJ.

garden N.
gate N.
gave V.
get V.
give V.
glad ADJ.
glass N.
goat N.
going V.
gone V.
good ADJ.
got V.
go V.
grass N.
gray ADJ.
grandmother N.
grandfather N.
green ADJ.
grew V.
great ADJ.
ground N.
grow V.

had V.
hair N.
happy ADJ.
hard ADJ.
has V.
hat N.
have V.
hear V.
head N.
heavy ADJ.
heard V.
held V.
help V.
hello INT.
hen N.
her DET.
here ADV.
he PRO.
hide V.
high ADJ.
hill N.
him PRO.
himself PRO.
his DET.
hit V.
hole N.
hold V.
home N.
hope V.
horse N.
hospital N.
hot ADJ.
house N.
how ADV.
huge ADJ.
hunt V.
hungry ADJ.
hurry V.
husband N.

idea N.
if CONJ.
important ADJ.
indian N.
into PREP.
in PREP.
is V.
its DET.
it PRO.
i PRO.

job N.
jump V.
jumped V.
just ADV.

keep V.
kept V.
king N.
kind N.
kitten N.
kitchen N.
knew V.
know V.

lake N.
land N.
last ADJ.
late ADJ.
laughed V.
lay V.
lazy ADJ.
led V.
left V.
let V.
letter N.
life N.
lift V.
light N.
line N.
lion N.
listen V.
little ADJ.
log N.
long ADJ.
loose ADJ.
lost ADJ.
lose V.
lot ID.
loud ADJ.
love V.
low ADJ.
lucky ADJ.
lunch N.

machine N.
made V.
make V.
man N.DET.
march V.
matter N.
may V.
meat N.
mean V.
meet V.
men N.
met V.
me PRO.
middle N.
might V.
milk N.
minute N.
mind V.
mirror N.
miss V.
money N.
more DET.
most PRO.
mother N.
mouse N.
mouth N.
mountain N.
move V.
mrs N.
mr N.
much ADJ.
must V.
my DET.

near PREP.
nearer PREP.
neck N.
need V.
never ADV.
new ADJ.
next ADJ.
nice ADJ.
night N.
noise N.
north N.
nose N.
not ADV.
nothing PRO.
now ADV.
no DET.

oak N.
off ADV.
office N.
often ADV.
of PREP.
oh INT.
old ADJ.
once ADV.
one DET.
only ADJ.
on PREP.
open V.
or CONJ.
other DET.
our DET.
out ADV.
over PREP.
owl N.
own ADJ.

pail N.
paint V.
palace N.
paper N.
park N.
part N.
parade N.
path N.
paw N.
pay V.
pen N.
pencil N.
penny N.
people N.
perhaps ADV.
pet N.
picnic N.
pie N.
pilot N.
pile N.
pink ADJ.
play V.
place N.
please INT.
policeman N.
polite ADJ.
pole N.
poor ADJ.
pop V.
porch N.
pretty ADJ.
prince N.
princess N.
prize N.
promise N.
proud ADJ.
pull V.
pumpkin N.
put V.

queen N.
quiet ADJ.
quick ADJ.
quite ADV.
quickly ADV.

rabbit N.
race N.
rain N.
ran V.
rang V.
read V.
really ADV.
ready ADJ.
real ADJ.
red ADJ.
remember V.
rest N.
ride V.
right ADJ.
ring N.
river N.
road N.
rode V.
roof N.
room N.
rope N.
round ADJ.
row N.
run V.
running V.

sad ADJ.
safe ADJ.
said V.
salt N.
same ADJ.
sang V.
sat V.
saturday N.
save V.
saw V.
say V.
scare V.
school N.
sea N.
seat N.
second ADJ.
secret N.
see V.
seen V.
sell V.
sent V.
send V.
set V.
seven DET.
several DET.
shall V.
she PRO.
short ADJ.
shot V.
shook V.
shoulder N.
shop V.
should V.
shut V.
side N.
sight N.
silver N.
silly ADJ.
sing V.
sister N.
sit V.
six DET.
sky N.
sleep V.
slowly ADV.
small ADJ.
smile V.
smoke N.
snow N.
soft ADJ.
some DET.
something PRO.
song N.
soon ADV.
sorry ADJ.
soup N.
sound N.
so ADV.
spend V.
splash V.
spoke V.
spring N.
spread V.
stay V.
station N.
stand V.
step N.
still ADV.
stick N.
stop V.
stopped V.
stood V.
store N.
story N.
stories N.
strong ADJ.
strange ADJ.
street N.
straight ADJ.
such ADJ.
suddenly ADV.
sugar N.
summer N.
sun N.
supper N.
sure ADJ.
sweet ADJ.
swim V.

table N.
tail N.
take V.
tall ADJ.
talk V.
teacher N.
tell V.
telephone N.
ten DET.
terrible ADJ.
that PRO.
than CONJ.
the DET.
them PRO.
these DET.
then ADV.
there ADV.
their DET.
this DET.
think V.
thought V.
three DET.
through PREP.
threw V.
thunder N.
time N.
tiny ADJ.
tired ADJ.
today N.
together ADV.
told V.
tomorrow N.
tongue N.
too ADV.
took V.
top N.
town N.
toward PREP.
to PREP.
trade V.
train N.
trap N.
tree N.
trip N.
tried V.
truck N.
trunk N.
try V.
turn V.
twelve DET.
two DET.
uncle N.
under PREP.
until CONJ.
up ADV.
use V.
us PRO.
very ADV.
village N.
visit V.
voice N.

wagon N.
wait V.
walk V.
wall N.
wanted V.
warm ADJ.
was V.
water N.
way N.
wear V.
well ADV.
went V.
were V.
west N.
wet ADJ.
we PRO.
what PRO.
when ADV.
where ADV.
wheel N.
which ADJ.
white ADJ.
while CONJ.
who PRO.
whole ADJ.
why ADV.
wide ADJ.
wife N.
will V.
wild ADJ.
winter N.
window N.
win V.
wind N.
wing N.
wish V.
wise ADJ.
with PREP.
woke V.
wolf N.
wonderful ADJ.
wonder V.
work V.
world N.
word N.
would V.
write V.
wrong ADJ.

yard N.
yellow ADJ.
yes INT.
yet ADV.
you PRO.
your DET.
young ADJ.

zoo N.

APPENDIX B

OUTLINE OF LANGUAGE ARTS FOR THE DEAF
(1972 - 73 VERSION)

Lesson	Name	Description
1.	INTROD	Introduction to the course
2.	DIR1	Directions: first, second, last letter
3.	DIR2	Directions: after
4.	DIR3	Directions: first, second, third, fourth, last word
5.	DIR4	Directions: after, before, words
6.	DIR5	Directions: first, second, third, fourth, last, after the first, before the last, letters
7.	DIR6	Directions: more than one word (spaces between)
8.	DIR7	Directions: more than one word; first, second, third, fourth, last, before the last words
9.	DIR8	Directions: below, under
10.	DIR9	Directions: above, below, under
11.	RTA	Review test
12.	NAA	Common nouns, introduction
13.	NAB	Common nouns, continued
14.	DAA	Determiners introduced (a, an, the)
15.	MAA	Mixed drill: identification of nouns and determiners
16.	MAB	Mixed drill: nouns and determiners
17.	MAC	Mixed drill: nouns and determiners
18.	LAA	Vowels introduced
19.	DAB	Determiners: use of "a" and "an"
20.	MAD	Identification of nouns and determiners
21.	RTB	Review test
22.	NPAA	Introduction of noun phrase (determiner noun)
23.	NPAB	Noun phrase (single noun)
24.	DAC	Cardinals as determiners

25.	NAC	Plural nouns introduced
26.	NAD	Plural nouns (-s)
27.	NAE	Plural nouns (-s, -es)
28.	NAF	Plural nouns (-ies)
29.	NAG	Plural nouns, all types
30.	NAH	Plural nouns, irregular
31.	RTC	Review test
32.	DAD	Determiner-noun agreement in number (one,two)
33.	MAE	Identification of nouns and determiners (some, every, no)
34.	NPAC	Review noun phrases (including new determiners)
35.	DAE	Determiner-noun agreement (a, some)
36.	DAF	Review determiners (a, some)
37.	DAG	Determiner noun agreement (a, an, some)
38.	VAA	Verbs introduced (one-word verbs)
39.	VAB	One-word verbs, indentification
40.	MAF	Mixed review: verbs, determiners, nouns
41.	VAC	Review one and two word verbs
42.	MAG	Mixed drill: identify noun phrases and verbs
43.	RTD	Review test
44.	VAD	Models introduced as part of two word verbs
45.	AJAA	Adjectives introduced (color, shape and size)
46.	AJAB	Adjectives (identify two in sentence)
47.	MAH	Mixed drill: nouns, adjectives, determiners, verbs
48.	MAI	Mixed drill: nouns, adjectives, determiners, verbs
50.	NPAD	Identify noun phrases with adjectives
51.	NPAE	Noun phrases with adjectives
52.	NPAF	First and second noun phrases
53.	AJAC	Predicate adjectives introduced

54.	MAJ	Mixed review: noun phrases and verbs
55.	RTE	Review test
56.	NPAG	Nominative noun phrases ("who", "what" questions)
57.	NPAH	Objective noun phrases ("what" questions)
58.	NPAI	Objective noun phrases ("what" questions without adverbials in question)
59.	NPAJ	Nominative and objective noun phrases ("who", "what" questions)
60.	NPAK	Nominative and objective noun phrases ("who", "what" questions)
61.	NPAL	Nominative and objective noun phrases ("who", "what" questions) (without adverbials in question)
62.	AJAD	Adjective transform introduced (subject noun phrase)
63.	AJAE	Adjective transform (position of adjective)
64.	AJAF	Adjective transform (object noun phrase)
65.	AJAG	Adjective transform (position of adjective)
66.	RTF	Review test
67.	SAA	Sentences: subject and predicate introduced
68.	SAB	Subject and predicate, continued
69.	PNAA	Pronouns introduced (I, you, we, he, she, it, they)
70.	PNAB	Pronouns introduced (me, him, her, it, us, them)
71.	NPAM	Pronouns as noun phrases
72.	SAC	Subject and predicate (pronoun subjects)
73.	PNAC	Pronoun-antecedent agreement (he, she, it)
74.	PNAD	Pronoun-antecedent agreement ("her father," "his sister")
75.	NPAN	Review singular and plural noun phrases
76.	PNAE	Pronoun-antecedent agreement (it, they)
77.	PNAF	Pronoun-antecedent agreement (he, she, it, they)
78.	RTG	Review test
79.	MAK	Mixed review: identify nouns and pronouns

80.	MAL	Mixed review: determiners, adjectives, nouns, verbs, pronouns
81.	PNAG	Pronoun-antecedent agreement (it, them)
82.	PNAH	Pronoun-antecedent agreement (her, him, it, them)
83.	SAD	Review subject and predicate
84.	PNAI	Pronoun-antecedent agreement (she, her, he, him)
85.	PNAJ	Pronoun-antecedent agreement (them, they)
86.	PNAK	Pronoun-antecedent agreement (them, they) (some compound subjects and objects)
87.	PNAL	Review of all pronoun-antecedent agreement
88.	RTH	Review test
89.	NPAO	Singular and plural noun phrases, including pronouns
90.	DAH	Determiner introduced (all)
91.	DAI	Determiner-noun agreement (all, every)
92.	DAJ	Double determiners (with "all" and cardinals)
93.	NPAP	Singular and plural noun phrases
94.	NAI	Review irregular plural nouns
95.	DAK	Review determiner number (a, an, some, cardinals)
96.	NAJ	Plural nouns with same form as singular
97.	NAK	Mixed review of plural nouns
98.	DAL	Singular and plural noun phrases (using "some" and "every")
99.	RTI	Review test
100.	SUAA	Identify subjects; some sentences beginning with adverbs
101.	SUAB	Singular and plural subjects
102.	SUAC	Singular and plural subjects
103.	SUAD	Compound subjects introduced
104.	SUAE	Singular and plural subjects, some compound
105.	SUAF	Number of subject; some sentences with adverbs

106.	VAE	Subject-verb agreement (choose the verb)
107.	VAF	Subject-verb agreement (choose the subject)
108.	VAG	Subject-verb agreement (some pronoun subjects) (choose the verb)
109.	RTJ	Review test
110.	VAH	Subject-verb agreement; some pronoun subjects including "I" and "you" (choose the verb)
111.	VAI	Subject-verb agreement; some pronoun subjects (choose the subject)
112.	VAJ	Subject-verb agreement; compound subjects (choose the verb)
113.	VAK	Subject-verb agreement; plural possessive pronouns with singular subjects (choose the verb)
114.	VAL	Subject-verb agreement; several kinds of subjects (choose the verb)
115.	VAM	Subject-verb agreement (choose subject or verb)
116.	SUAG	Number of subject; some irregular nouns
117.	SUAH	Number of subject; some nouns with same singular and plural
118.	RTK	Review test
119.	VAN	Subject-verb agreement; some nouns with same singular and plural (choose the verb)
120.	VAO	Subject-verb agreement (choose subject or verb)
121.	VAP	Y-ies inflections introduced
122.	VAQ	S-form of verbs ending in y: cry, stay, etc.
123.	VAR	-es inflection of verbs ending in -ch, -sh, -s, -x, -z
124.	VAS	Spelling of -es and s-forms
125.	VAT	Drill on s-forms; go-goes and do-does introduced
126.	VAU	S-form of HAVE introduced
127.	VAV	Mixed drill on s-form; change from plural to singular subjects
128.	RTL	Review test
129.	PRAA	Introduce "prepositon" (in, to, of)

130.	PRAB	Identify prepositions (introduce for, with, on)
131.	PRAC	Introduce "prepositional phrase" (only PREP DET N)
132.	PRAD	Identify prepositional phrases (introduce at, by, from)
133.	PRAE	Identify prepositional phrases of several forms: PREP N, PREP DET N, PREP ADJ N, PREP DET ADJ N
134.	PRAF	Identify prepositional phrases of several forms (introduce after, into, over, before)
135.	PRAG	Identify first or second prepositional phrase
136.	BEAA	Introduce "is-are" forms (with compound subjects)
137.	BEAB	"is," "am," "are" with various subjects
138.	BEAC	Review "is," "am," "are" with constructed answers
139.	RTM	Review test
140.	VAW	Subject-verb (-s) agreement; some is-am-are (choose the verb)
141.	VAX	Subject-verb (-es) agreement; some is-am-are (choose the verb)
142.	VAY	Subject-verb agreement, some is-am-are (choose the noun or pronoun)
143.	VAZ	Spelling of s-forms; drill on "is" and "are"
144.	VBA	Review of s-forms: HAVE, GO, DO
145.	VBB	Review of s-forms: HAVE, GO, DO; constructed answers
146.	PRAH	Identify prepositional phrases of place
147.	PRAI	Prepositional phrases of place (fill in missing preposition)
148.	PRAJ	Prepositional phrases of place (choose correct preposition)
149.	RTN	Review test
150.	PRAK	Identify prepositional phrases of time
151.	PRAL	Prepositional phrases of time (fill in missing preposition)
152.	PRAM	Prepositional phrases of time (choose correct preposition)

153.	VBC	Introduce past tense
154.	VBD	Past tense construction (adding -d and -ed)
155.	VBE	Spelling of y-ied past tense
156.	VBF	Spelling of past tense with doubling of consonant
157.	VBG	Review of past tense; also HAVE, GO, DO
158.	VBH	Review of past tense; various verbs
159.	VBI	Change s-form to simple form of verb
160.	RTO	Review test
161.	VBJ	Present participles; "ing-form" introduced
162.	VBK	ing-forms with doubling of consonant
163.	VBL	ing-forms with dropping of final 'e'
164.	VBM	Review ing-forms; constructed answers
165.	VBN	Present progressive subject-verb agreement
166.	VBO	Present progressive subject-verb agreement; some constructed answers
167.	VBP	Present progressive agreement with pronouns; some constructed answers
168.	VBQ	"Present progressive" introduced; construct both parts
169.	VBR	Change from present to present progessive; construct both parts
170.	RTP	Review test
171.	SAE	Negative transform; "not-sentence" introduced, modals
8 9	SAF	Negative transform; insert "not" correctly
173.	NPAQ	"possessive noun phrase" introduced (subjects only)
174	NPAR	Identify possessive noun phrases (subjects and objects)
175.	NPAS	Possessive transform; identify correct sentence
176.	NPAT	Possessive noun phrase, singular nouns; contructed answers
177.	NPAU	Possessive noun phrase, plural nouns; constructed answers

178.	RTQ	Review test
179.	PRAN	Prepositional phrases of place and time (choose correct preposition)
180.	PRAO	Prepositional phrases of place and time (insert correct preposition)
181.	PRAP	Prepositional phrases of place and time (insert correct preposition)
182.	PRAQ	Prepositional phrases ("when" questions)
183.	PRAR	Prepositional phrases ("where" questions)
184.	PRAS	prepositional phrases ("when" and "where" questions
185.	VBS	Review past tense and present progessive; -ed, -ing
186.	VBT	Past tense and present progressive; -d, drop 'e' + ing
187.	VBU	Past tense and present progressive; y-ied, double consonant verbs
188.	VBV	Past tense and present progressive; various verbs
189.	RTR	Review test
190.	BEAD	Contractions of BE introduced; identify contraction
191.	BEAE	Contractions of BE; pronouns (constructed answers)
192.	BEAF	BE contractions; noun phrases (constructed answers)
193.	BEAG	Change BE contractions; pronouns (constructed answers)
194.	BEAH	Change BE contractions; noun phrases (constructed answers)
195.	NPAV	Possessive pronouns introduced
196.	NPAW	Possessive noun phrase, pronouns; constructed answers
197.	NPAX	Possessive noun phrase, pronouns; constructed answers
198.	NPAY	Possessive noun phrase, nouns and pronouns; constructed answers
199.	RTS	Review test
200.	SAG	Negative transform; forms of HAVE and BE
201.	SAH	Negative transform; insert "not" in sentence; HAVE and BE

202.	SAI	Review negative transform; HAVE, BE, and modals
203.	MAM	Negative contractions introduced; HAVE, BE, and DO
204.	MAN	Negative contractions; BE (constructed answers)
205.	MAO	Negative contractions; HAVE, BE, DO (constructed answers)
206.	MAP	Change negative contractions; BE (constructed answers)
207.	MAQ	Change negative contractions; HAVE, BE, DO (constructed answers)
208.	RTT	Review test
209.	NPAZ	Noun phrases ("who," "what" questions)
210.	PRAT	Prepositional phrases ("when," "where" questions)
211.	MAR	Mixed review ("who," "what," "when," and "where" questions) (three questions for one statement)
212.	MAS	Mixed review ("who," "what," "when," and "where" questions) (three questions for one statement)
213.	SAJ	Identify modal, have-word or be-word
214.	SAK	Introduce question transform; type modal, have-word or be-word (CA gives transform)
215.	SAL	Question transform; "type the modal or the have-word or the be-word" (CA gives transform)
216.	SAM	Question transform; identify correct sentence
217.	RTU	Review test

APPENDIX C

Specific Objectives of the Language Arts Curriculum with Lessons and Subtests Cross-referenced

The objectives of the G-course, Language Arts for the Deaf, are listed. The lessons of the G-course covering that objective, and the subtests of the 1971 IMSSS Language Test covering that objective are given for each objective.

Objective D(a)

TYPE ANY LETTER OR LETTERS IN A GIVEN WORD IDENTIFIED BY ONE OF THE FOLLOWING: ORDINALS ("FIRST" THROUGH "FOURTH"), "AFTER THE FIRST," "FIRST TWO," "LAST," "BEFORE THE LAST," "LAST TWO."

Lessons
DIR4,DIR5, DIR6, DIR8, DIR9, DIR11, DIR12, DIR13, DIR14, DIR15, DIR16, DIR17, DIR18

This objective was not tested because the same ordinals are covered in the next objective, and in the test these ordinals are not used to specify letters, but only to specify words.

Objective D(b)

TYPE ANY WORD OR WORDS IN A GIVEN SENTENCE IDENTIFIED BY ONE OF THE FOLLOWING: ORDINALS ("FIRST" THROUGH "FOURTH"), "AFTER" OR "BEFORE" A GIVEN WORD, "BEFORE THE LAST."

Lessons
DIR1, DIR2, DIR3, DIR6, DIR7, DIR10, DIR20

SUBTEST 1

Objective D(c)

COPY ON THE TELETYPE A TWO OR THREE-WORD PHRASE FROM A GIVEN SENTENCE, INCLUDING THE SPACE BETWEEN WORDS.

Lessons
DIR19

This objective is not tested because it is only important in order to correctly input answers into the computer.

Objective D(d)

GIVEN TWO OR THREE ROWS OF NUMBERS (EACH ROW CONTAINING UP TO FIVE NUMBERS), TYPE ANY NUMBER WHOSE POSITION IS SPECIFIED BY "ABOVE," "BELOW," OR "UNDER" ANOTHER NUMBER.

Lessons
DIR21, DIR22, DIR23, DIR24, DIR25

This objective was not tested because it is only important in order to correctly respond when asked to type the number under a specific word. This response method is used in the G-course but not in the test.

Objective 1(a)

IDENTIFY ONE OR MORE NOUNS, IN EITHER A NOMINATIVE OR OBJECTIVE POSITION.

Lessons
NAA, NAB, MAA, MAB, MAC, MAD, MAE, NPAC, MAF, MAH, MAI, MAL, MAM

SUBTEST 2

Objective 1(b)

IDENTIFY ONE OR MORE OF THE FOLLOWING AS DETERMINERS "A," "AN," "THE," "SOME," "EVERY," "NO," "ALL," CARDINAL NUMBERS FROM "ONE" TO "TEN," AND DOUBLE DETERMINERS WITH "ALL" OR CARDINALS.

Lessons
DAA, MAA, MAB, MAC, MAD, MAE, DAC, MAF, MAH, MAI, MAM, DAI, DAK

SUBTEST 3

Objective 1(c)

IDENTIFY ISOLATED VOWELS, AND SELECT FROM A GROUP OF WORDS THE ONE THAT STARTS WITH A VOWEL.

Lesson
LAA

This objective was not tested because it is not a final objective but only preparation for the correct use of "a" and "an", which is tested in subtest 6.

Objective 1(d)

IDENTIFY NOUN PHRASES (APPEARING IN EITHER A NOMINATIVE OR OBJECTIVE POSITION) OF THE FOLLOWING TYPES: SINGLE NOUN OR PRONOUN, DETERMINER-NOUN, DETERMINER-ADJECTIVE-NOUN, DETERMINER-DETERMINER-NOUN, ADJECTIVE-NOUN, DETERMINER-ADJECTIVE-ADJECTIVE-NOUN. NOUN PHRASES MAY BE ORDINALLY SPECIFIED, SPECIFIED AS SINGULAR OR PLURAL, OR SPECIFIED AS POSSESSIVE.

lessons
NPAA, NPAB, NPAC, MAG, NPAD, NPAE, NPAF, MAJ, MAK, NPAG, NPAH, NPAI, NPAJ, NPAK, NPAL, NPAM, DAN, NPAN

SUBTEST 5

Objective 1(e)

SELECT FROM A GIVEN SENTENCE ONE OR MORE NOUNS SPECIFIED AS SINGULAR OR PLURAL

lesson
NAC

This objective was not tested because it is not a final objective but only preparation for writing plural forms of nouns, which is tested in subtest 10.

Objective 1(f)

IDENTIFY AS VERBS, VERBS IN THE SIMPLE PRESENT, PRESENT PROGRESSIVE, SIMPLE PAST, PAST PROGRESSIVE OR MODAL FORM.

lessons
VAA, VAB, MAF, VAC, VAD, MAG, VAE, MAH, MAI, MAJ, MAK, MAM

SUBTEST 4

Objective 1(g)

IDENTIFY AS MODALS: "CAN," "COULD," "WILL," "WOULD," "SHOULD," "MAY," "MIGHT," "MUST"

lesson
SAE

This objective was not tested because it is not a final objective but only preparation for making a correct negative transform, which is tested in subtest 11.

Objective 1(h)

IDENTIFY FROM A GIVEN SENTENCE ONE OR MORE NOMINATIVE OR PREDICATE ADJECTIVES.

lessons
AJAA, AJAB, AJAC, MAH, MAI, AJAD, MAK, MAM

SUBTEST 2

Objective 1(i)

IDENTIFY THE COMPLETE SUBJECT (EITHER SIMPLE OR COMPOUND) AND THE COMPLETE PREDICATE OF A GIVEN SENTENCE AND INDICATE WHETHER THE SUBJECT IS SINGULAR OR PLURAL.

lessons
SAA, SAB, SUAA, SUAB, SUAC, SUAD, SUAE, SUAF, SUAG, SUAH, SAC, SAD

This objective was not tested because it is very similar to the identification of noun phrases specified as singular or plural, which is tested in subtest 5.

Objective 1(j)

IDENTIFY AS PRONOUNS: "HE," "SHE," "IT," "THEY," "I," "YOU," "WE," "ME," "HIM," "HER," "US" AND "THEM;" AND AS POSSESSIVE PRONOUNS: "MY," "HIS," "HER," "ITS," "YOUR," "OUR" AND "THEIR."

lessons
PNAA, PNAB, PNAC, MAL, MAM, NPAR

SUBTEST 2

Objective 1(k)

GIVEN A DECLARATIVE SENTENCE AND A RELATED QUESTION, IDENTIFY THE NOMINATIVE OR OBJECTIVE NOUN PHRASE THAT ANSWERS THE QUESTION.

lessons
NPAG, NPAH, NPAI

This objective was not tested because it was included in the course not as a final objective, but to give practice identifying specific noun phrases, which is tested in subtest 5.

Objective 2(a)

SUPPLY THE PLURALS OF GIVEN SINGULAR NOUNS, AND THE SINGULARS OF GIVEN PLURAL NOUNS, BOTH REGULAR AND IRREGULAR. (REGULAR NOUNS INCLUDE THOSE WHOSE PLURALS ARE FORMED BY ADDING -S, -ES, (Y)-IES OR (F)-VES. IRREGULAR NOUNS GIVEN ARE: "MAN," "WOMAN," "CHILD," "FOOT," "MOUSE," "SHEEP," "DEER," "ASPIRIN" AND "OFFSPRING."

lessons
NAD, NAE, NAF, NAG, NAH, NAI, NAJ, NAK

SUBTEST 10

Objective 2(b)

INDICATE WHETHER A SPECIFIED NOUN PHRASE IS SINGULAR OR PLURAL.

lessons
NPAK, NPAL, NPAM

This objective is not tested because it is not a final objective, but only preparation for identifying noun phrases specified as singular or plural, which is tested in subtest 5.

Objective 2(c)

GIVEN THE ROOT FORM OF A VERB, SUPPLY THE GENDER MARKED FORM (THIRD PERSON SINGULAR), SIMPLE PAST, OR PRESENT PARTICPLE. VERBS GIVEN ARE REGULAR (INCLUDING THOSE ENDING WITH SINGLE CONSONANTS AND -Y) AND THE IRREGULAR VERBS "HAVE," "GO" AND "DO" IN THE THIRD PERSON SINGULAR AND PAST FORMS.

lessons

VAL, VAM, VAN, VAO, VAP, VAQ, VAQM, VAR, VAS, VAVT, VAY, VAZ, VBA, VBB, VBC, VBCM, VBD, VBE, VBF, VBG, VBH, VBI, VBJ

This objective was not tested because of the difficulty of correcting constructed answers, and because the final objective, choosing the correct verb form to complete a sentence, is tested in subtest 9.

Objective 3(a)

TYPE "A" OR "AN" BEFORE A GIVEN NOUN IN A SENTENCE, DEPENDING ON THE FIRST LETTER OF THE NOUN.

lessons
DAB, DAG, DAH, DAL

SUBTEST 6

Objective 3(b)

CHOOSE, FROM TWO GIVEN DETERMINERS, THE ONE THAT AGREES IN NUMBER WITH A GIVEN SINGULAR OR PLURAL NOUN IN A SENTENCE.

lessons
DAC, DAD, DAE, DAF, DAH, DAI, DAJ, DAL, DAM

SUBTEST 6

Objective 3(c)

CHOOSE, FROM TWO GIVEN PRONOUNS, THE ONE THAT IS APPROPRIATE EITHER IN NUMBER OR GENDER OR CASE OR ALL THREE TO THE NOUN PHRASE THAT IT WILL REPLACE.

lessons
PNAD, PNAE, PNAF, PNAG, PNAH, PNAI, PNAJ, PNAK, PNAL

SUBTEST 8

Objective 3(d)

CHOOSE THE CORRECT INFLECTION OF A VERB BASED ON SUBJECT VERB AGREEMENT IN NUMBER

lessons
VAF, VAG, VAH, VAHM, VAI, VAJ, VAK, VAT, VAU, VAV, VAVM, VAW, VBP, VBQ, VBR, VBS

SUBTEST 9

Objective 3(e)

CHOOSE THE CORRECT INFLECTION OF THE PRESENT TENSE OF "BE" TO COMPLETE A SENTENCE.

lessons
BEAA, BEAB, BEAC, BEAD, BEAE, BEAF, BEAG, BEAH, BEAI, VAI, VAV, VBK, VBL, VBM, VBN, VBO, VBP, VBQ, VBR, VBS

SUBTEST 14

Objective 3(f)

GIVEN THE ROOT FORM OF A VERB, CONSTRUCT THE CORRECT FORM OF THE PRESENT PROGRESSIVE TO COMPLETE A SENTENCE.

lessons
VBG, VBH, VBI, VBJ, VBL, VBM, VBN, VBO

This objective was not tested because of the difficulty of correcting constructed answers. Identification of the present progressive as a verb is tested in subtest 4, and choosing the correct inflection of the present tense of "BE" to complete a sentence with the present progressive is tested in subtest 14.

Objective 4(a)

COMBINE TWO RELATED SENTENCES INTO ONE BY SPECIFYING THE POSITION OF AN ADJECTIVE TO BE INSERTED.

lessons
AJAE, AJAF, AJAG, AJAH

SUBTEST 12

Objective 4(b)

INDICATE THE NEGATIVE TRANSFORM OF A GIVEN SENTENCE (INCLUDING A MODAL, A FORM OF "HAVE" OR A FORM OF "BE") BY SPECIFYING THE POSITION OF "NOT."

lessons
SAF, SAG, SAH, SAI, SAJ, SAK

SUBTEST 11

Objective 4(c)

CONSTRUCT A POSSSESSIVE NOUN PHRASE FROM A SENTENCE OF THE FORM: NOUN PHRASE, FORM OF "HAVE," NOUN PHRASE.

lessons
NPAO, NPAP, NPAQ, NPAS, NPAT

SUBTEST 13

Objective 4(d)

EXPAND A CONTRACTION OF "BE" FROM A GIVEN SENTENCE.

lessons
BEAL, BEAM

SUBTEST 15

Objective 4(e)

MAKE A CONTRACTION WITH "BE" AND A PRONOUN OR NOUN PHRASE.

lessons
BEAJ, BEAK

SUBTEST 15

Objective 4(f)

EXPAND A NEGATIVE CONTRACTION OF "BE," "HAVE" OR "DO" FROM A GIVEN SENTENCE.

lessons
MAN, MAO, MAP

SUBTEST 15

APPENDIX D

Curriculum Objectives not Covered by the Language Arts Test

The following specific objectives of the course, Language Arts for the Deaf, are not covered by the test. Many of these are interim objectives and only the final objective was tested.

D(a) Type any letter or letters in a given word identified by one of the following: ordinals ("first" through "fourth"), "after the first," "first two," "last," "before the last," "last two."

D(c) Copy on the teletype a two- or three-word phrase from a given sentence, including the space between words.

D(d) Given two or three rows of numbers (each row containing up to three numbers), type any number whose position is specified by "above," "below," or "under" another number.

1(c) Identify isolated vowels, and select from a group of words the one that starts with a vowel.

1(e) Select from a given sentence one or more nouns specified as singular or plural

1(g) Identify as modals: "can," "could," "will," "would," "should," "may," "might," "must."

1(i) Identify the complete subject (either simple or compound) and the complete predicate of a given sentence, and indicate whether the subject is singular or plural.

1(k) Given a declarative sentence and a related question, identify the nominative or objective noun phrase that answers the question.

2(b) Indicate whether a specified noun phrase is singular or plural.

2(c) Given the root form of the verb, supply the gender marked form (third person singular), simple past, or present participle. Verbs given are regular (including those ending with single consonants and -y) and the irregular verbs "have," "go," and "do" in the third person singular and past forms.

3(f) Given the root form of a verb, construct the correct form of the present progressive to complete a sentence.

APPENDIX E

100 Most Frequently Occurring Words in SAMPLE

574	i	33	like
523	the	33	morning
431	and	33	up
422	to	32	god
367	my	32	new
249	a	30	good
162	in	30	want
158	was	29	him
144	we	28	all
141	is	27	am
135	he	27	family
135	went	27	from
112	at	27	girls
110	last	27	has
107	of	26	sunday
103	it	26	were
97	on	25	afternoon
95	for	25	bought
75	me	25	boys
73	that	25	room
71	home	25	them
67	said	25	yesterday
66	some	24	saw
61	will	24	so
61	with	24	there
59	his	23	happy
58	house	23	king-midas
57	our	23	play
55	mother	23	when
52	saturday	22	back
48	but	22	came
48	gold	22	told
47	about	21	day
46	you	21	school
45	then	21	watched
42	they	20	after
41	father	20	ate
41	her	20	bedroom
40	because	20	daughter
40	go	20	many
39	are	20	see
39	brother	19	by
39	friday	19	friends
39	she	19	got
39	two	19	man
39	very	19	other
38	have	19	put
38	night	19	touch
35	had	19	00
35	one	18	bus

APPENDIX F

Brief Description of Context-free Grammars
and Probabilistic Grammars

The following is a brief discussion of the notions of context-free grammar and probabilistic grammar. These notions are more fully described by Suppes (1970) from both formal and methodological points of view.

Let V be a set of symbols. Then, V^* is the set of all finite sequences of elements of V, including the empty string, which is denoted by ε. Such finite sequences are sometimes called strings. V^+ denotes $V^* - \{\varepsilon\}$. Small letters a,b,c, are variables ranging over members of V^*.

A structure,

$$G = \langle V, VT, S, P \rangle$$

is a generative grammar just in case G satisfies the following conditions:

1) V is a finite nonempty set of symbols, the vocabulary;

2) VT is a nonempty subset of V, known as the terminal vocabulary (the nonterminal vocabulary $VN = V - VT$);

3) S is a distinguished element of VN, called the start symbol;

4) P, the set of productions or rules, is a finite subset of the set $V^+ \times V^*$.

Let VT^+ be the set of all finite nonempty terminal strings. Further, if $\langle a,b \rangle \in P$, then we write (informally)

$$a \rightarrow b$$

to indicate that this is a production in P. a is the left-hand side (lhs) of $\langle a,b \rangle$ and b is the right-hand-side (rhs) of $\langle a,b \rangle$.

If a,b are strings in V^*, then b is immediately produced from a if and only if there is a subsequence a' in a and a subsequence b' in b such that b is the result of substituting b' in a for a', and such that

$$a' \rightarrow b'$$

is a rule in P. The intuition here is that an immediate production is what one obtains by replacing into some string for the left-hand side of some production by the right-hand-side of that production.

If a,b are in V* , then b is derivable from a if and only if there exist

a1, a2, ..., an for some n

such that

a (immediately) produces a1
a1 produces a2
a2 produces a3
⋮
an produces b .

The sequence ⟨a,a1⟩ ⟨a1,a2⟩, ..., ⟨an,b⟩ is called a derivation of b from a .

As an example of these ideas, consider the following grammar G that generates a few English sentences.

G = ⟨V,VT,S,P⟩

where

V = {S,NP,VP,N,ART,V,a,the,boy,girl,sees,knows,runs}

and

VT = {the,boy,girl,sees,knows,runs} .

Hence, the set VN of non-terminals is

VN = {S,NP,VP,N,ART,V} .

S is the start symbol (for sentence).

P contains the following rules:

S → NP
NP → N
NP → ART N
VP → V
VP → V NP
N → boy N → girl
ART → a ART → the
V → runs V → sees V → knows

Hence, S produces NP VP . Also, the string

the boy

is derivable from the string NP . This relationship is denoted by

$$NP \underset{G}{\Rightarrow} \text{the boy}$$

where G (a reference to the grammar) may be omitted when the grammar is clear.

The set of noun phrases is the set of all terminal strings derivable from the symbol NP . What we are interested in is the set of terminal strings in VT+ that is derivable from the start symbol, i.e.,

$$\{a \in VT+ \mid S \underset{G}{\Rightarrow} a\} .$$

This is the language of the grammar G , denoted by L(G) .

Different kinds of generative grammars are obtained by putting restrictions on the production rules that may be in P . A type 0 or recursively enumerable grammar has no further restrictions placed upon it. A type 1 or context-sensitive grammar has only the restriction that if $\langle a,b \rangle$ is in P then $|b| \geq |a|$, where $|a|$ is the number of symbols in a , the length of a . A type 2 or context-free grammar is context-sensitive plus if $\langle a,b \rangle$ is in P then $|a|=1$; further, only non-terminals may occur on the left-hand side of the derivation.

Informally, let a context-free grammar G be a set of rewrite rules of the form

$$A \rightarrow B1 \ B2 \ \ldots \ Bn ,$$

where n is any natural number, together with a start symbol S . The non-terminal symbols of G are the symbols that do not occur on the right-hand side of any rule, and the terminal symbols are the other symbols. Only a finite number of symbols and a finite number of rules are involved in a context-free grammar. The language of the grammar is the set of all strings of symbols that can be derived by an application of the rewrite rules starting with the start symbol.

Further, let us attach to each rule p of the grammar G a parameter a(p) that is, intuitively, the conditional probability that the rule will be applied assuming that some rule with a given left-hand side is to be used. Each parameter must be in the interval [0,1] in order to be a meaningful probability. Also, the sum of the parameters associated with the rules with a given left-hand side must be 1, in order to be consistent with the notion of conditional probability.

Then, by a simple method described in Suppes (1970), it is possible to estimate the parameters for the rules of the grammar G such that the probability of getting the empirical distribution observed in the data is at a maximum; further, it is possible to test the goodness of fit by the standard chi-square test.